6.4 Conversion of Energy from One Form to Other .... 6 - 13
6.5 Introduction to Batteries .... 6 - 19

Section B : Batteries

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6.7 Lead Acid Battery .... 6 - 21
6.8 Lithium Ion Battery .... 6 - 26
6.9 Characteristics of Battery .... 6 - 30
6.10 Concept of Depth of Discharging .... 6 - 32
6.11 Maintenance of Batteries .... 6 - 33
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Question Bank for End Sem Exam (Q - 1) to (Q - 7)

Solved Sample Question Papers (End Sem) (SE - 1) to (SE - 22)

Sample Question Paper - 1 (End Sem) (SE - 1) to (SE - 5)
Sample Question Paper - 2 (End Sem) (SE - 5) to (SE - 9)
Sample Question Paper - 3 (End Sem) (SE - 10) to (SE - 13)
Sample Question Paper - 4 (End Sem) (SE - 14) to (SE - 18)
Sample Question Paper - 5 (End Sem) (SE - 18) to (SE - 22)

MARKING SCHEME

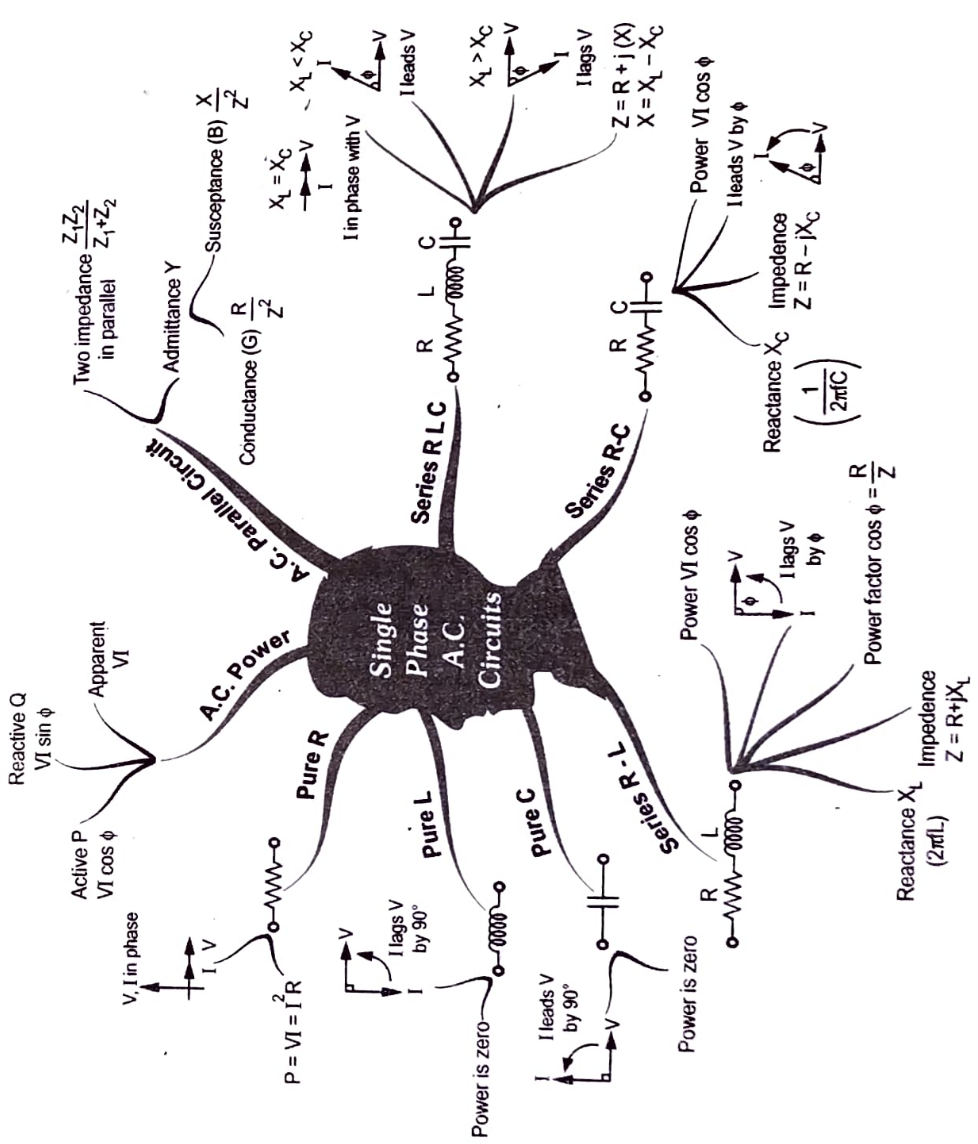
EXAMINATION SCHEME & QUESTION PAPER PATTERN

End Sem Exam

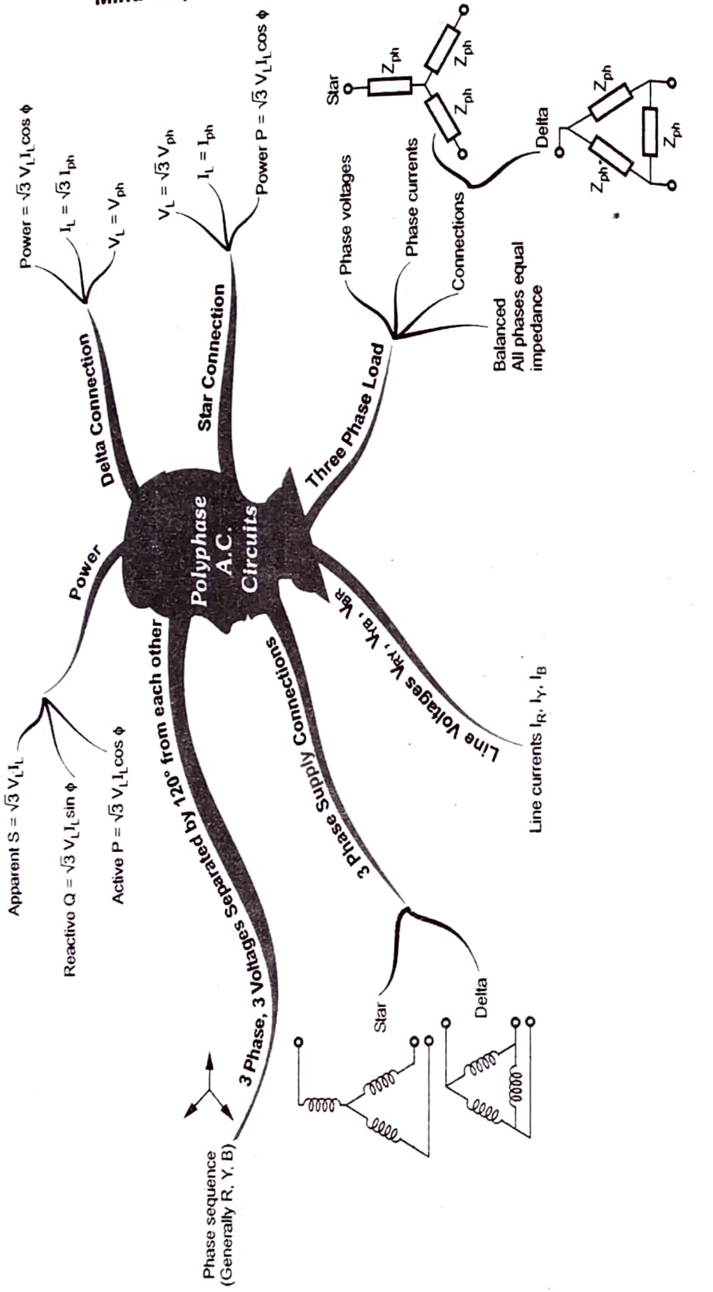
Q.1 or Q.2	Unit - III	18 Marks	$2\frac{1}{2}$ Hours 70 Marks
Q.3 or Q.4	Unit - IV	17 Marks	
Q.5 or Q.6	Unit - V	18 Marks	
Q.7 or Q.8	Unit - VI	17 Marks	

MIND MAPS

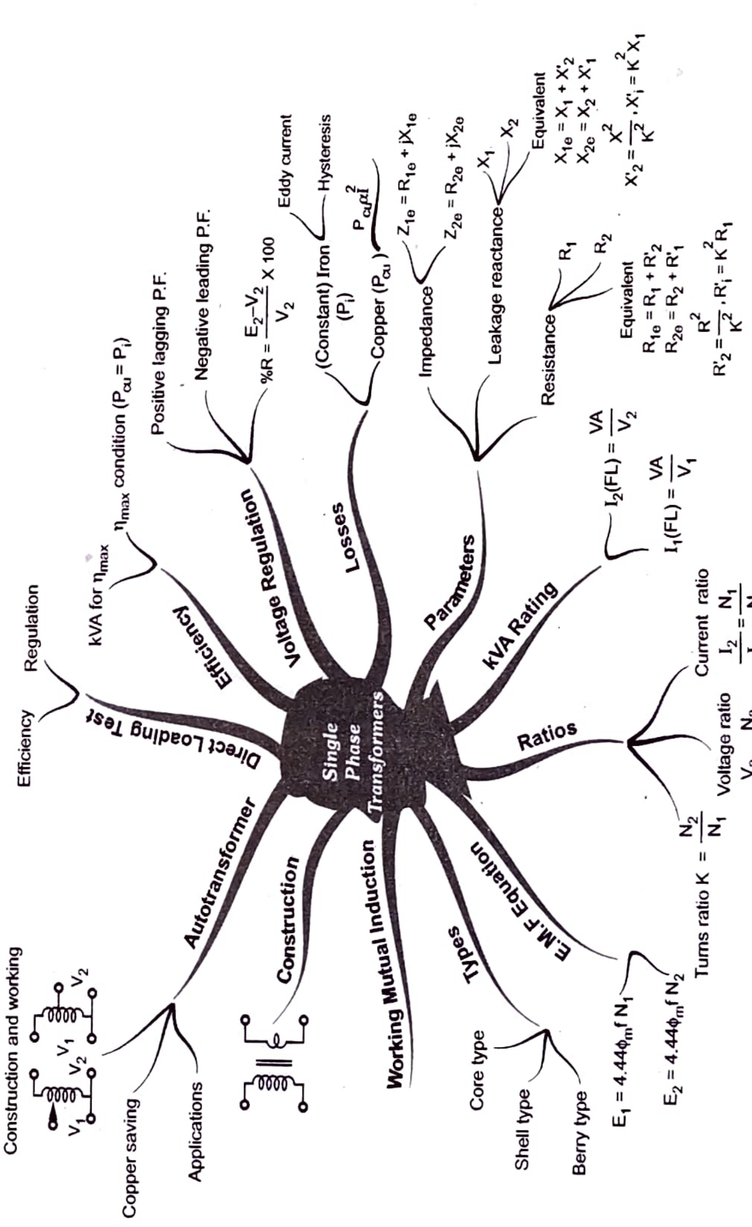
Mind Map : Unit III : Single Phase A.C. Circuits


Single Phase A.C. Circuits
A.C. Parallel Circuit
Two impedance in parallel $\frac{Z_1Z_2}{Z_1+Z_2}$
Admittance Y
Conductance (G) $\frac{R}{Z^2}$
Susceptance (B) $\frac{X}{Z^2}$
Series R L C
R L C
$X_L = X_C$
I in phase with V
$X_L < X_C$
I leads V
$X_L > X_C$
I lags V
$Z = R + j(X)$
$X = X_L - X_C$
Series R-C
R C
Power VI cos ϕ
I leads V by ϕ
Impedence $Z = R - jX_C$
Reactance X_C $\left(\frac{1}{2\pi fC}\right)$
Series R - L
R L
Power VI cos ϕ
I lags V by ϕ
Power factor cos ϕ = $\frac{R}{Z}$
Impedance $Z = R + jX_L$
Reactance X_L $(2\pi fL)$
Pure C
Power is zero
I leads V by 90°
Pure L
Power is zero
I lags V by 90°
Pure R
$P = VI = I^2R$
V, I in phase
A.C. Power
Apparent VI
Reactive Q VI sin ϕ
Active P VI cos ϕ

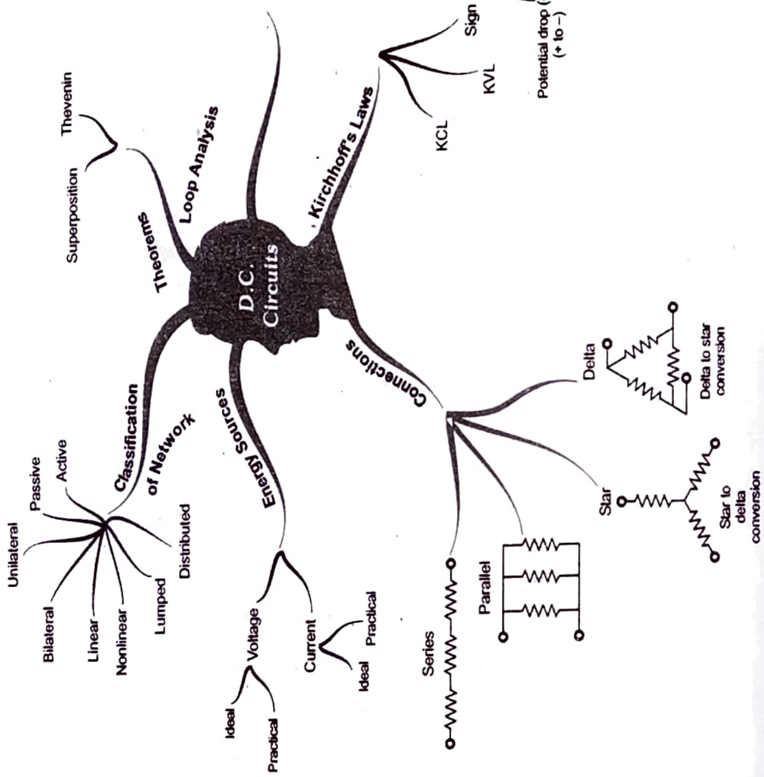
Mind Map - Unit IV - Polyphase A.C. Circuits


Polyphase A.C. Circuits
Delta Connection
Power = $\sqrt{3}\, V_L I_L \cos\phi$
$I_L = \sqrt{3}\, I_{ph}$
$V_L = V_{ph}$
Star Connection
$V_L = \sqrt{3}\, V_{ph}$
$I_L = I_{ph}$
Power P = $\sqrt{3}\, V_L I_L \cos\phi$
Three Phase Load
Phase voltages
Phase currents
Connections
Balanced All phases equal impedance
Star
Z_{ph}
Delta
Line Voltages V_{RY}, V_{YB}, V_{BR}
Line currents I_R, I_Y, I_B
3 Phase Supply Connections
Star
Delta
3 Phase, 3 Voltages Separated by 120° from each other
Phase sequence (Generally R, Y, B)
Power
Apparent S = $\sqrt{3}\, V_L I_L$
Reactive Q = $\sqrt{3}\, V_L I_L \sin\phi$
Active P = $\sqrt{3}\, V_L I_L \cos\phi$

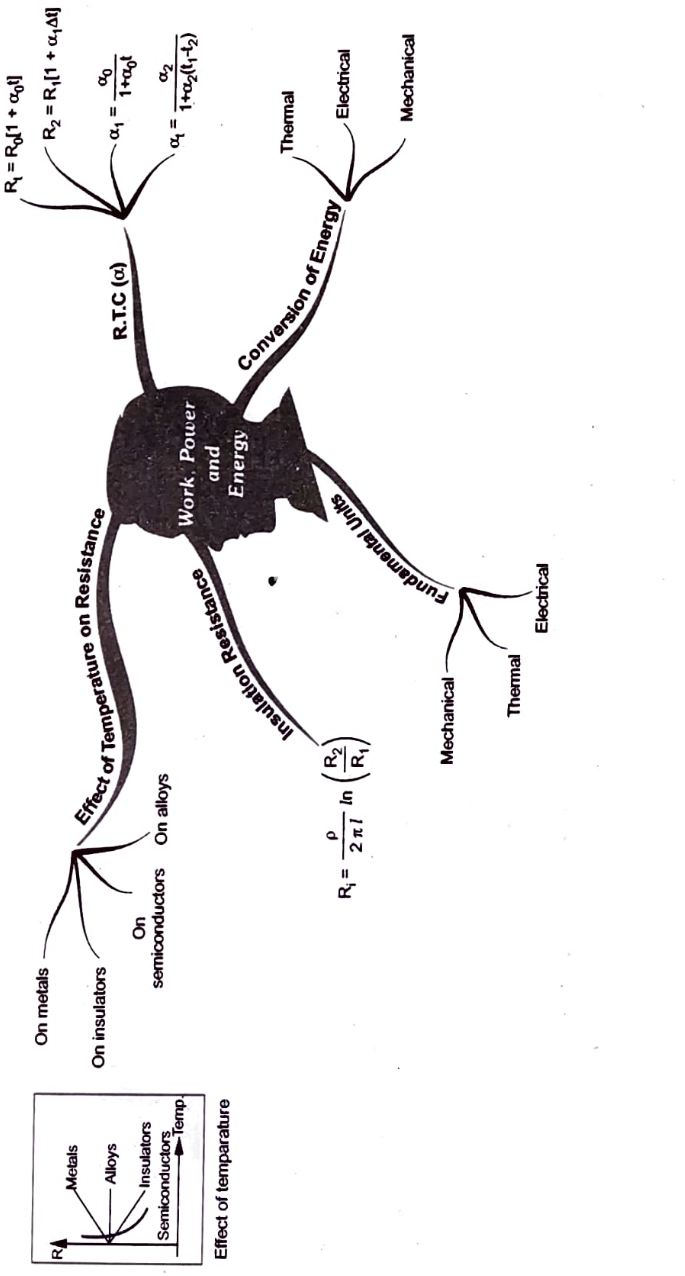
Mind Map - Unit IV : Single Phase Transformers


Single Phase Transformers
Direct Loading Test
Efficiency
Regulation
Efficiency
kVA for η_{max}
η_{max} condition ($P_{cu} = P_i$)
Voltage Regulation
Positive lagging P.F.
Negative leading P.F.
%R = $\frac{E_2 - V_2}{V_2} \times 100$
Losses
(Constant) Iron (P_i)
Eddy current
Hysteresis
Copper (P_{cu})
$P_{cu} \alpha I^2$
Parameters
Impedance
$Z_{1e} = R_{1e} + jX_{1e}$
$Z_{2e} = R_{2e} + jX_{2e}$
Leakage reactance
X_1
X_2
Equivalent
$X_{1e} = X_1 + X'_2$
$X_{2e} = X_2 + X'_1$
$X'_2 = \frac{X_2}{K^2}, X'_1 = K^2 X_1$
Resistance
R_1
R_2
Equivalent
$R_{1e} = R_1 + R'_2$
$R_{2e} = R_2 + R'_1$
$R'_2 = \frac{R_2}{K^2}, R'_1 = K^2 R_1$
kVA Rating
$I_1(FL) = \frac{VA}{V_1}$
$I_2(FL) = \frac{VA}{V_2}$
Ratios
Current ratio $\frac{I_2}{I_1} = \frac{N_1}{N_2}$
Voltage ratio $\frac{V_2}{V_1} = \frac{N_2}{N_1}$
E.M.F Equation
Turns ratio K = $\frac{N_2}{N_1}$
$E_1 = 4.44 \phi_m f N_1$
$E_2 = 4.44 \phi_m f N_2$
Types
Core type
Shell type
Berry type
Working Mutual Induction
Construction
Autotransformer
Construction and working
V_1
V_2
Copper saving
Applications

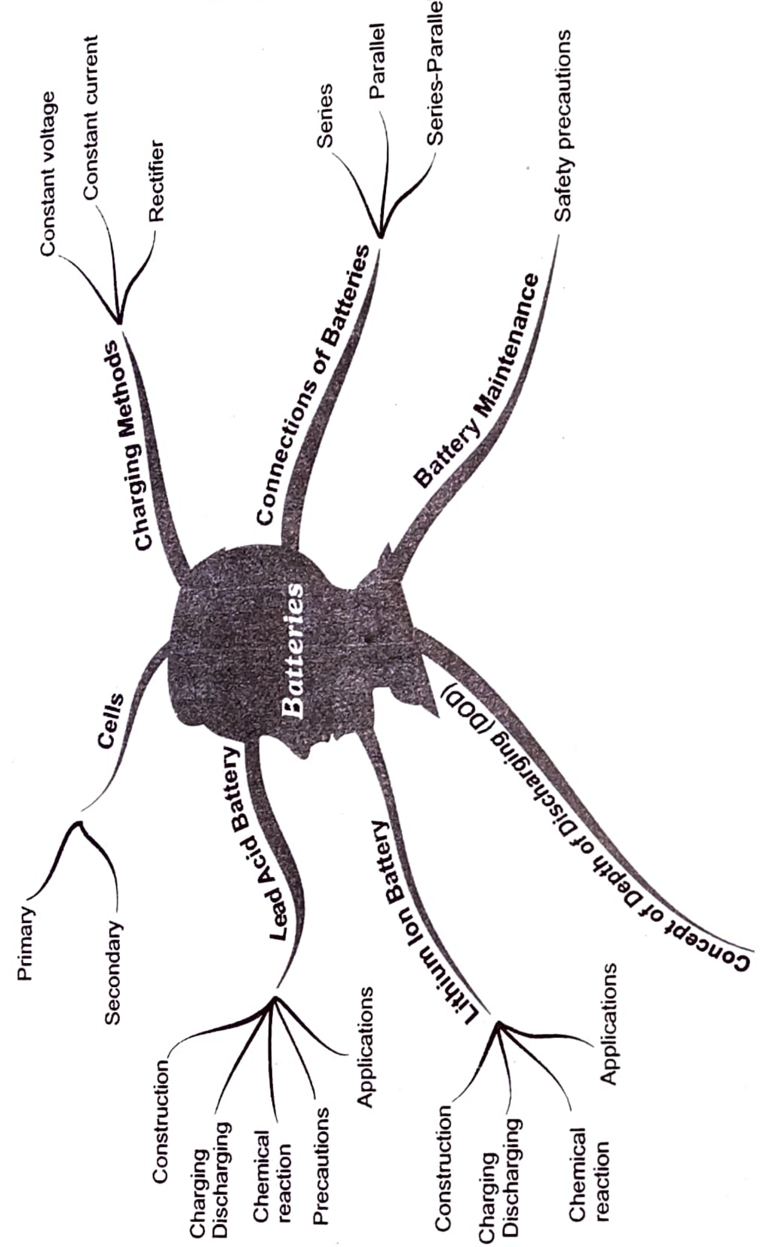
Mind Map : Unit V : D.C. Circuits


D.C. Circuits
Theorems
Superposition
Thevenin
Loop Analysis
Kirchhoff's Laws
KCL
KVL
Sign conventions
Potential drop (−ve) (+ to −)
Potential rise (+ve) (− to +)
Connections
Delta
Delta to star conversion
Star
Star to delta conversion
Parallel
Series
Energy Sources
Voltage
Ideal
Practical
Current
Ideal
Practical
Classification of Network
Passive
Active
Unilateral
Bilateral
Linear
Nonlinear
Lumped
Distributed

Mind Map : Unit VI : Work, Power and Energy


Work, Power and Energy
R.T.C (α)
$R_t = R_0[1 + \alpha_0 t]$
$R_2 = R_1[1 + \alpha_1 \Delta t]$
$\alpha_1 = \frac{\alpha_0}{1+\alpha_0 t}$
$\alpha_1 = \frac{\alpha_2}{1+\alpha_2(t_1-t_2)}$
Conversion of Energy
Thermal
Electrical
Mechanical
Fundamental Units
Mechanical
Thermal
Electrical
Insulation Resistance
$R_i = \frac{\rho}{2\pi l} \ln\left(\frac{R_2}{R_1}\right)$
Effect of Temperature on Resistance
On metals
On insulators
On semiconductors
On alloys
R
Metals
Alloys
Insulators
Semiconductors
Temp.
Effect of temparature

Mind Map : Unit VI : Batteries


Batteries
Charging Methods
Constant voltage
Constant current
Rectifier
Connections of Batteries
Series
Parallel
Series-Parallel
Battery Maintenance
Safety precautions
Concept of Depth of Discharging (DOD)
Cells
Primary
Secondary
Lead Acid Battery
Construction
Charging Discharging
Chemical reaction
Precautions
Applications
Lithium Ion Battery
Construction
Charging Discharging
Chemical reaction
Applications

UNIT - III

3

Single Phase A.C. Circuits

3.1 : A.C. through Pure Resistance

Q.1 Prove that the voltage and current in purely resistive circuit are in phase. ☞ **[SPPU : Dec.-05, May-18, Marks 4]**

Ans. : Consider a simple circuit consisting of a pure resistance 'R' ohms connected across a voltage $v = V_m \sin \omega t$.

- The circuit is shown in the Fig. Q.1.1.

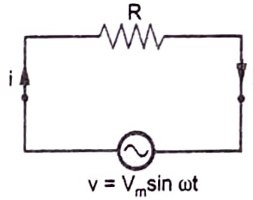

R
i
i
v = V_m sin ωt

Fig. Q.1.1 Pure resistive circuit

- According to Ohm's law, we can find the equation for the current i as,

$$i = \frac{v}{R} = \frac{V_m \sin \omega t}{R} \quad \text{i.e.} \quad i = \left(\frac{V_m}{R}\right) \sin (\omega t)$$

- This is the equation giving instantaneous value of the current.
- Comparing this with standard equation, $i = I_m \sin (\omega t + \phi)$

$$\boxed{I_m = \frac{V_m}{R} \quad \text{and} \quad \phi = 0^\circ}$$

- So, maximum value of alternating current, i is $I_m = \frac{V_m}{R}$ while as $\phi = 0$, it indicates that it is in phase with the voltage applied.
- The waveforms of voltage and current and the corresponding phasor diagram is shown in the Fig. Q.1.2 (a) and (b).

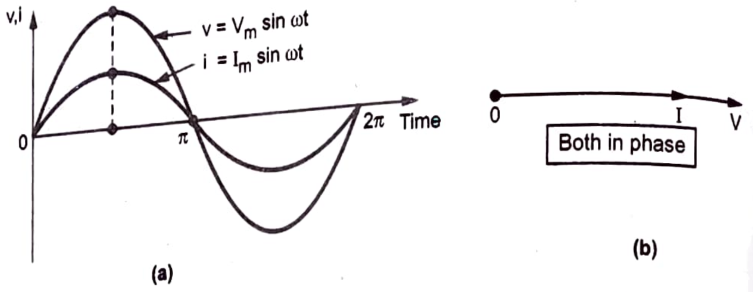


Fig. Q.1.2 A.C. through purely resistive circuit

Q.2 Derive an expression for the instantaneous power in a purely resistive circuit excited by sinusoidal voltage. ☞ **[SPPU : May-18, Marks 3]**

Ans. : The instantaneous power in a.c. circuits can be obtained by taking product of the instantaneous values of current and voltage.

$$P = v \times i = V_m \sin(\omega t) \times I_m \sin \omega t$$

$$= V_m I_m \sin^2(\omega t) = \frac{V_m I_m}{2}(1 - \cos 2\omega t)$$

$$\therefore \quad \boxed{P = \frac{V_m I_m}{2} - \frac{V_m I_m}{2} \cos(2\omega t)}$$

- From the above equation, it is clear that the instantaneous power consists of two components,

  1) Constant power component $\left(\frac{V_m I_m}{2}\right)$

  2) Fluctuating component $\left[\frac{V_m I_m}{2} \cos(2\omega t)\right]$ having frequency, double the frequency of the applied voltage.

- **The average value of the fluctuating cosine component of double frequency is zero, over one complete cycle.**
- So, average power consumption over one cycle is equal to the constant power component i.e. $\frac{V_m I_m}{2}$ which is half of the peak power $V_m I_m$.

$$\therefore \quad \boxed{P_{av} = \frac{V_m I_m}{2} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = V_{rms} \times I_{rms} \text{ watts}}$$

- Generally, r.m.s. values are indicated by capital letters.

$$\therefore \quad \boxed{P_{av} = V \times I \text{ watts} = I^2 R \text{ watts}}$$

Q.3 The expression of the alternating current is given by $i = 5.48 \sin \omega t$. Calculate : i) the average value, ii) rms value of the current iii) power consumed if the current is passed through a resistance of 10 Ω. ☞ **[SPPU : May-15, Marks 6]**

Ans. : $i = 5.48 \sin \omega t = I_m \sin \omega t$ i.e. $I_m = 5.48\text{A}$

i) $I_{av} = 0.637\, I_m = \mathbf{3.4909A}$ ii) $I_{rms} = \frac{I_m}{\sqrt{2}} = \mathbf{3.8749A}$

iii) $P = I_{rms}^2 \times R = (3.8749)^2 \times 10 = \mathbf{150.15\ W}$

Q.4 The alternating current expression is given by i = 14.14 sin (100 πt) Amp. Determine : i] maximum value of current ii] RMS value of current iii] average value of current iv] form factor v] peak factor vi] power consumed when it flows through resistance of 10 Ω. ☞ **[SPPU : May-19, Marks 7]**

Ans. : Given : $i(t) = 14.14 \sin(100\pi t)$, $R = 10\ \Omega$

To find : $I_m, I_{rms}, I_{av}, K_f, K_p, P$

Comparing $i(t) = I_m \sin(\omega t)$

i) $I_m = \mathbf{14.14\ A}$ ... Maximum

ii) $I_{rms} = \frac{I_m}{\sqrt{2}} = \mathbf{10\ A}$ ... RMS

iii) $I_{av} = 0.637\, I_m = \mathbf{9\ A}$ ... Average

iv) $K_f = \frac{\text{rms}}{\text{Average}} = \frac{10}{9} = \mathbf{1.11}$ ... Form factor

v) $K_p = \frac{\text{Maximum}}{\text{rms}} = \mathbf{1.414}$ ... Peak factor

vi) $P = V_{rms} \times I_{rms}$ but $I_{rms} = \frac{V_{rms}}{R}$

$\therefore \quad P = I_{rms}^2 \times R = 10^2 \times 10 = \mathbf{1\ kW}$

3.2 : A.C. through Pure Inductance

Q.5 Derive the expressions for current and power for purely inductive circuit when the voltage applied to it is $v(t) = V_m \sin \omega t$. Draw the corresponding phasor diagram.

☞ [SPPU : May-08,14,15,17, Dec.-08, Marks 6]

OR Prove that in a purely inductive circuit the current lags voltage by 90°.

☞ [SPPU : May-11, Marks 4]

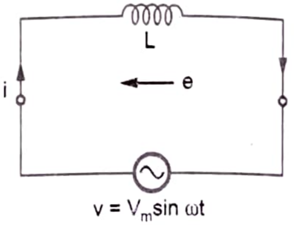


Fig. Q.5.1 Purely inductive circuit

Ans. : Consider a pure inductance of L henries, connected across a voltage given by the equation, $v = V_m \sin \omega t$ as shown in the Fig. Q.5.1.

- When alternating current 'i' flows through inductance 'L', it sets up an alternating magnetic field around the inductance.
- This changing flux links the coil and due to self inductance, e.m.f. gets induced in the coil. This e.m.f. opposes the applied voltage.
- The self induced e.m.f. in the coil is given by, $e = -L \frac{di}{dt}$.
- At all instants, applied voltage, v is equal and opposite to the self induced e.m.f., e.

$$\therefore \quad v = -e = -\left(-L\frac{di}{dt}\right)$$

$$\therefore \quad v = L\frac{di}{dt} \quad \text{i.e.} \quad V_m \sin \omega t = L\frac{di}{dt} \quad \text{i.e.} \quad di = \frac{V_m}{L} \sin \omega t \, dt$$

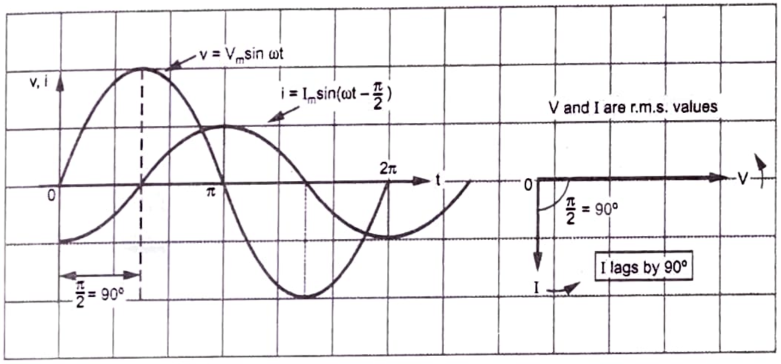
$$\therefore \quad i = \int di = \int \frac{V_m}{L} \sin \omega t \, dt = \frac{V_m}{L}\left(\frac{-\cos \omega t}{\omega}\right)$$

$$= -\frac{V_m}{\omega L} \sin\left(\frac{\pi}{2} - \omega t\right) \qquad \ldots \cos \omega t = \sin\left(\frac{\pi}{2} - \omega t\right)$$

$$\therefore \quad i = \frac{V_m}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right) \qquad \ldots \sin\left(\frac{\pi}{2} - \omega t\right) = -\sin\left(\omega t - \frac{\pi}{2}\right)$$

$$\therefore \quad \boxed{i = I_m \sin\left(\omega t - \frac{\pi}{2}\right) \text{ where } I_m = \frac{V_m}{\omega L} = \frac{V_m}{X_L} \text{ and } X_L = \omega L = 2\pi f L \ \Omega}$$

- The above equation clearly shows that the current is purely sinusoidal and having phase angle of $-\frac{\pi}{2}$ radians i.e. − 90°. This means that **the current lags voltage applied by 90°.**
- The Fig. Q.5.2 shows the waveforms and the corresponding phasor diagram.



(a) Waveforms (b) Phasor diagram

Fig. Q.5.2 A.C. through purely inductive circuit

- The expression for the instantaneous power can be obtained by taking the product of instantaneous voltage and current.

$$\therefore \quad p = v \times i = V_m \sin \omega t \times I_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$= -V_m I_m \sin(\omega t) \cos(\omega t) \quad \text{as } \sin\left(\omega t - \frac{\pi}{2}\right) = -\cos \omega t$$

$$\therefore \quad \boxed{p = -\frac{V_m I_m}{2} \sin(2\omega t)} \quad \text{as } 2 \sin \omega t \cos \omega t = \sin 2\omega t$$

- This power curve is a sine curve of frequency double than that of applied voltage.

- The average value of sine curve over a complete cycle is always zero.

$$P_{av} = \int_0^{2\pi} -\frac{V_m I_m}{2} \sin(2\omega t)\, d(\omega t) = 0$$

- Pure inductance never consumes power.

Important Points to Remember

- The **inductive reactance** is defined as the opposition offered by the inductance of a circuit to the flow of an alternating sinusoidal current.
- It is measured in ohms and it depends on the frequency of the applied voltage.
- Mathematically it is given by,

$$X_L = \omega L = 2\pi f L\ \Omega$$

Q.6 Draw the waveforms for voltage, current and power for a pure inductance when excited by sinusoidal voltage.

Ans. : The waveforms are shown in the Fig. Q.6.1.

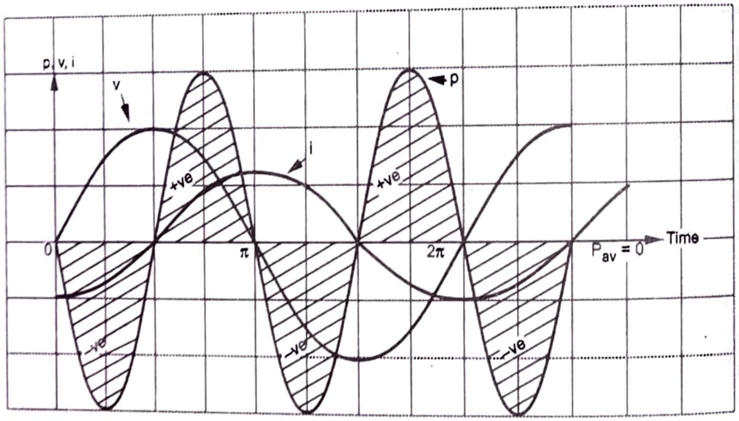


Fig. Q.6.1 Waveforms of voltage, current and power for pure L

Q.7 Find the expression for current which will flow when a pure inductor of 0.2 H is connected across 230 V, 50 Hz, AC supply. Draw the phasor diagram. **[SPPU : Dec.-16, Marks 6]**

Ans. : L = 0.2 H, V = 230 V, f = 50 Hz

$$\therefore \quad X_L = 2\pi f L = 62.831\ \Omega$$

$$\therefore \quad Z = 0 + j X_L = 0 + j62.831\ \Omega = 62.831 \angle 90^\circ\ \Omega$$

$$\therefore \quad I = \frac{V}{Z} = \frac{230 \angle 0^\circ}{62.831 \angle 90^\circ} = 3.66 \angle -90^\circ\ \text{A}$$

$$\therefore \quad I_m = \sqrt{2}\, I = \sqrt{2} \times 3.66 = 5.177\ \text{A},$$

$$\omega = 2\pi f = 314.159\ \text{rad/s}$$

∴ Expression for the current is,

$$i = I_m \sin(\omega t - \phi)$$

$$\therefore \quad \mathbf{i = 5.177 \sin(314.159\, t - 90^\circ)\ A}$$

The phasor diagram is shown in the Fig. Q.7.1.

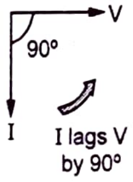


Fig. Q.7.1

3.3 A.C. through Pure Capacitance

Q.8 Derive the expressions for current and power for purely capacitive circuit when the voltage applied to it is $v(t) = V_m \sin \omega t$. Draw the corresponding phasor diagram. **[SPPU : May-06,08,18, Dec.-06, Marks 6]**

OR Prove that in a purely capacitive circuit the current leads voltage by 90°. **[SPPU : May-09,11, Dec.-05,17, Marks 4]**

Ans. : Consider a pure capacitance of C farads, connected across a voltage given by the equation, $v = V_m \sin \omega t$ as shown in the Fig. Q.8.1.

- The current i charges the capacitor C.

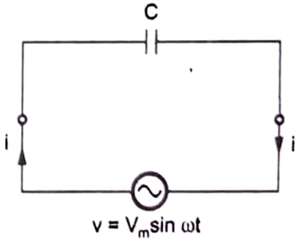


Fig. Q.8.1 Purely capacitive circuit

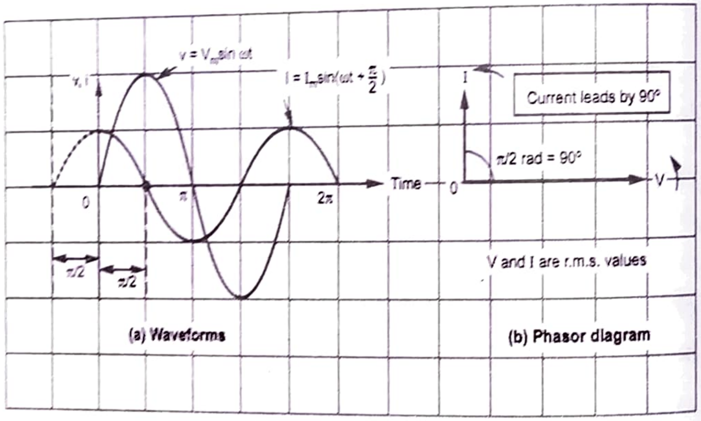
- The instantaneous charge 'q' on the plates of the capacitor is given by, $q = C\,v = C\,V_m \sin \omega t$
- Current is rate of flow of charge.

$$i = \frac{dq}{dt} = \frac{d}{dt}(C\,V_m \sin \omega t) = C\,V_m \frac{d}{dt}(\sin \omega t) = C\,V_m\,\omega \cos \omega t$$

$$\therefore \quad i = \frac{V_m}{\left(\frac{1}{\omega C}\right)} \sin\left(\omega t + \frac{\pi}{2}\right) = I_m \sin\left(\omega t + \frac{\pi}{2}\right) \qquad \dots (1)$$

where $\boxed{I_m = \frac{V_m}{X_C} \quad \text{and} \quad X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}\ \Omega}$

- The equation(1) clearly shows that the current is purely sinusoidal and having phase angle of $+\frac{\pi}{2}$ radians i.e. + 90°.
- This means **current leads voltage applied by 90°**. The positive sign indicates leading nature of the current.
- The Fig. Q.8.2 shows waveforms of voltage and current and the corresponding phasor diagram.



(a) Waveforms

(b) Phasor diagram

Fig. Q.8.2 A.C. through purely capacitive circuit

- The expression for the instantaneous power can be obtained by taking the product of instantaneous voltage and current.

$$p = v \times i = V_m \sin(\omega t) \times I_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$= V_m I_m \sin(\omega t)\cos(\omega t) \qquad \text{as } \sin\left(\omega t + \frac{\pi}{2}\right) = \cos \omega t$$

$$\therefore \quad \boxed{p = \frac{V_m I_m}{2} \sin(2\,\omega t)} \qquad \text{as } 2 \sin \omega t \cos \omega t = \sin 2\,\omega t$$

- Thus, power curve is a sine wave of frequency double that of applied voltage.
- **The average value of sine curve over a complete cycle is always zero.**

$$P_{av} = \int_0^{2\pi} \frac{V_m I_m}{2} \sin(2\,\omega t)\, d(\omega t) = 0$$

- The pure capacitor never consumes power.

Important Points to Remember

- The **capacitive reactance** is defined as the opposition offered by the capacitance of a circuit to the flow of an alternating sinusoidal current.
- X_C is measured in ohms and it is inversely proportional to the frequency.
- Mathematically it is given by,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} \quad \Omega$$

- Pure capacitance never consumes power.

Q.9 Draw the waveforms for voltage, current and power for a pure capacitance when excited by sinusoidal voltage.

Ans. : The waveforms are shown in the Fig. Q.9.1.

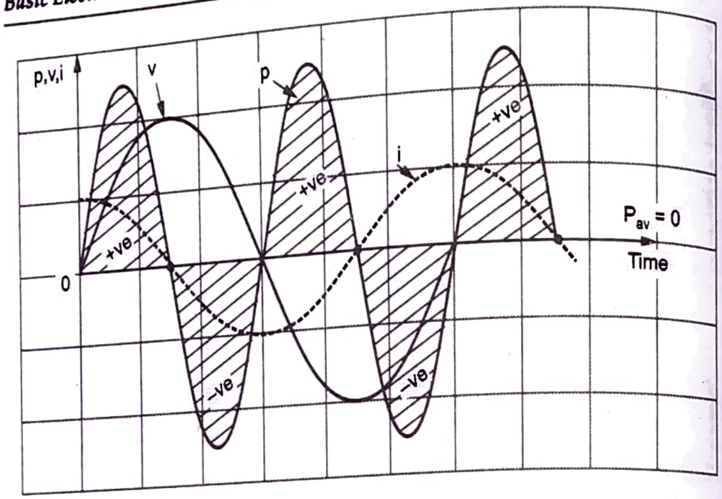


Fig. Q.9.1 Waveforms of voltage, current and power for pure C

3.4 : Impedance

Q.10 Define impedance.

Ans. : The opposition offered by an electric circuit to the flow of an alternating current is called an impedance. It is denoted by Z.

- It is the ratio of an alternating voltage to an alternating current through the circuit. Impedance is complex and is expressed in polar or rectangular form.

Important Points to Remember

- The impedances for pure R, pure L and pure C are mathematically expressed in rectangular and polar forms as,

$$Z = R + j0 = R \angle 0^\circ \text{ ohms.} \qquad \text{... Pure R}$$

$$Z = \frac{V\angle 0^\circ}{I\angle -90^\circ} = \frac{V}{I}\angle 90^\circ = X_L\angle 90^\circ = 0 + j\,X_L \text{ ohms} \qquad \text{... Pure L}$$

$$Z = \frac{V\angle 0^\circ}{I\angle +90^\circ} = \frac{V}{I}\angle -90^\circ = X_C\angle -90^\circ = 0 - j\,X_C \quad \text{... Pure C ohms}$$

- The above impedances must be used while solving the problems on a.c. circuits.

3.5 : Series R-L Circuit

Q.11 Derive the expression for the current for R-L series circuit when supplied by a voltage $v(t) = V_m \sin \omega t$. Draw the phasor diagram. ☞ **[SPPU : Dec.-09, May-04, 10, 19, Marks 6]**

Ans. : Consider a R-L series circuit as shown in the Fig. Q.11.1.

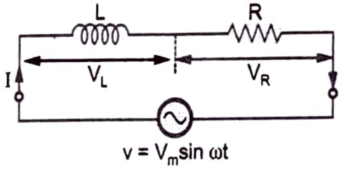


Fig. Q.11.1 Series R-L circuit

- When the circuit draws a current I then there are two voltage drops,

a) Drop across pure resistance, $V_R = I \times R$

b) Drop across pure inductance, $V_L = I \times X_L$ where $X_L = 2\pi f L$

I = r.m.s. value of current drawn

V_R , V_L = r.m.s. values of the voltage drops

- The Kirchhoff's voltage law can be applied to the a.c. circuit but only the point to remember is the addition of voltages should be a phasor (vector) addition and no longer algebraic as in case of d.c.

$$\therefore \qquad \boxed{\overline{V} = \overline{V_R} + \overline{V_L} = \overline{IR} + \overline{I\,X_L} \qquad \text{(Phasor addition)}}$$

- The phasor diagram for the above case is shown in the Fig. Q.11.2(a) while the voltage triangle is shown in the Fig. Q.11.2(b).

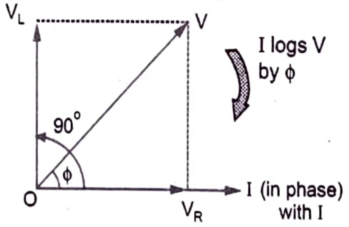


Fig. Q.11.2 (a) Phasor diagram

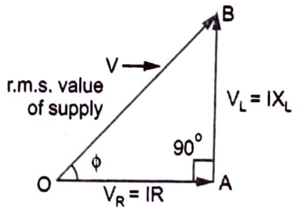


Fig. Q.11.2 (b) Voltage triangle

- Note that V_R is along the current phasor as for the resistance, voltage and current are in phase. While V_L must be drawn such that current lags V_L by 90°.
- From the voltage triangle, shown in the Fig. Q.11.2(b) we can write,

$$V = \sqrt{(V_R)^2 + (V_L)^2} = \sqrt{(IR)^2 + (I \times X_L)^2}$$

$$= I\sqrt{(R)^2 + (X_L)^2} = I\,Z$$

Where $\boxed{Z = \sqrt{(R)^2 + (X_L)^2}}$ ... **Impedance** of the circuit.

- It can be seen that current lags voltage by angle ϕ.

$$\therefore \quad \boxed{v(t) = V_m \sin \omega t \text{ and } i(t) = I_m \sin(\omega t - \phi)}$$

Q.12 For a single-phase a.c circuit, the applied voltage is $v = V_m \sin \omega t$ and current drawn is $i = I_m \sin(\omega t - \phi)$. Derive expression for average power. Draw waveforms of voltage, current and instantzneous power over one cycle of voltage.

☞ [SPPU : Dec.-11, 14, 15, 16, 17, May-12, 14, Marks 6]

Ans. : From the given equations of voltage and current, it is clear that the current lags the applied voltage by angle ϕ. Thus the circuit is series R-L circuit.

- The power is product of instantaneous values of voltage and current,

$$\therefore \quad P = v \times i = V_m \sin \omega t \times I_m \sin(\omega t - \phi)$$

$$= V_m I_m [\sin(\omega t) \, . \, \sin(\omega t - \phi)]$$

$$= V_m I_m \left[\frac{\cos(\phi) - \cos(2\,\omega t - \phi)}{2}\right]$$

$$= \frac{V_m I_m}{2} \cos\phi - \frac{V_m I_m}{2} \cos(2\,\omega t - \phi)$$

- Now, the second term is cosine term whose average value over a cycle is zero. Hence, average power consumed is,

$$P_{av} = \frac{V_m I_m}{2} \cos\phi = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos\phi$$

$$\therefore \quad \boxed{P = V\,I\cos\phi \text{ watts}}$$ where V and I are r.m.s. values

- The waveforms of voltage, current and power are shown in the Fig. Q.12.1.

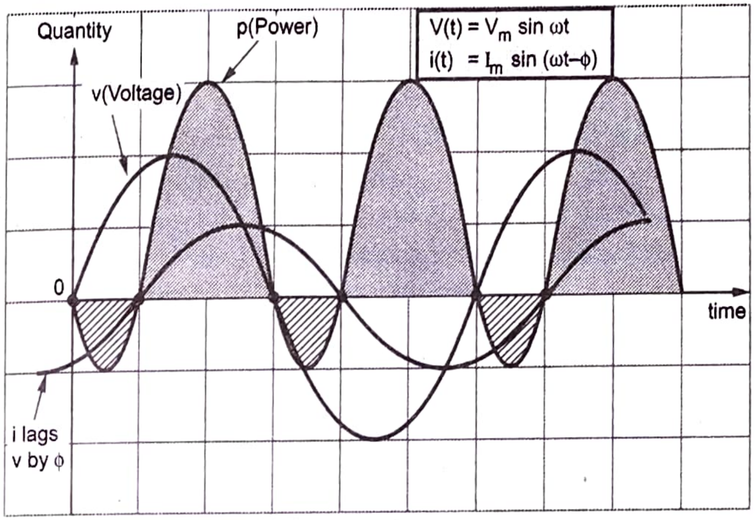


Fig. Q.12.1

Q.13 Define impedance and sketch an impedance triangle.

☞ [SPPU : Dec.-13. Marks 3]

Ans. : Impedance is defined as then opposition of circuit to flow of alternating current. It is denoted by Z and its unit is ohms.

- If all the sides of the voltage triangle are divided by the current, we get a triangle called **impedance triangle** as shown in the Fig. Q.13.1.

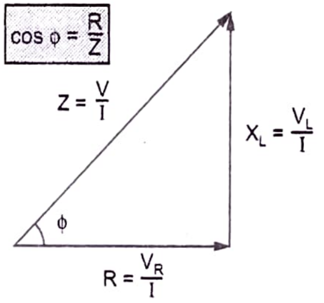


Fig. Q.13.1 Impedance triangle

- Sides of this triangle are resistance R, inductive reactance X_L and an impedance Z.

Q.14 Draw power triangle and define active power, reactive power and apparent power. **☞ [SPPU : Dec.-06, 10, May-08, Marks 4]**

Ans. : If we multiply voltage equation of R-L series circuit by current I, we get the power equation.

$$\overline{V}\,I = \overline{V_R}\,I + \overline{V_L}\,I = \overline{V}\cos\phi\,I + \overline{V}\sin\phi\,I$$

- From this equation, power triangle can be obtained as shown in the Fig. Q.14.1.
- The three sides of this triangle are,

1) VI, 2) VI cos ϕ, 3) VI sin ϕ

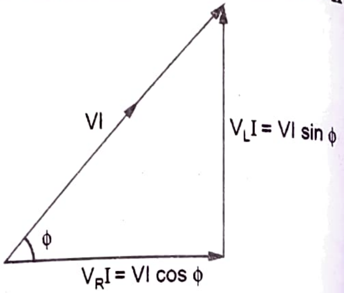


Fig. Q.14.1 Power triangle

1. Apparent Power (S)

It is defined as the product of r.m.s. value of voltage (V) and current (I). It is denoted by S.

$$\therefore\ \boxed{S = V\,I = \text{Apparent power} \quad \text{... measured in volt-amp (VA)}}$$

2. Real or True Power (P)

- It is defined as the product of the applied voltage and the active component of the current.
- It is real component of the apparent power. It is measured in unit watts (W) or kilowatts (kW).

$$\boxed{P = \text{True or active power} = V\,I\cos\phi \quad \text{watts}}$$

3. Reactive Power (Q)

- It is defined as product of the applied voltage and the reactive component of the current.
- It is also defined as imaginary component of the apparent power. It is represented by 'Q' and it is measured in unit volt-amp reactive (VAR) or kilovolt-amp reactive (kVAR).

$$\boxed{Q = \text{Reactive power} = V\,I\sin\phi \quad \text{VAR}}$$

Q.15 Define power factor. **☞ [SPPU : Dec.-03, 08, May-04, Marks 3]**

Ans. : It is defined as factor by which the apparent power must be multiplied in order to obtain the true power.

- It is the ratio of true power to apparent power.

$$\boxed{\text{Power factor} = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{V\,I\cos\phi}{V\,I} = \cos\phi}$$

- The numerical value of cosine of the phase angle between the applied voltage and the current drawn from the supply voltage is called the power factor. **It cannot be greater than 1.**
- It is also defined as the ratio of resistance to the impedance.

Important Points to Remember

- The nature of power factor is always determined by the position of the current with respect to the voltage.
- If current lags voltage, power factor is said to be lagging. If current leads voltage, power factor is said to be leading.
- For series R-L circuit, $Z = R + j X_L = |Z| \angle \phi \quad \Omega$

$$|Z| = \sqrt{R^2 + X_L^2},$$

$$\phi = \tan^{-1}\left[\frac{X_L}{R}\right], \quad \phi \text{ is positive for inductive impedance}$$

$$\text{Power factor} = \cos\phi = \frac{R}{Z}$$

Q.16 A coil having resistance of 7 Ω and an inductance of 31.8 mH is connected to 230 V, 50 Hz supply. Calculate : i) The circuit current ii) Phase angle iii) Power factor iv) Power consumed iv) Voltage drop across resistance and inductor. **☞ [SPPU : Dec.-16, Marks 6]**

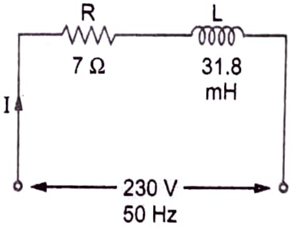


Fig. Q.16.1

Ans. : $R = 7\ \Omega,\ L = 31.8\ \text{mH},$

$$V = 230\ \text{V},\ f = 50\ \text{Hz}$$

$$X_L = 2\pi f L$$

$$= 2\pi \times 50 \times 31.8 \times 10^{-3} = 10\ \Omega$$

$\therefore Z = R + jX_L = 7 + j10 = 12.206 \angle 50^\circ \ \Omega$

i) $I = \frac{V}{Z} = \frac{230 \angle 0^\circ}{12.206 \angle 55^\circ} = 18.843 \angle -55^\circ$ A

Circuit current = **18.843 A**

ii) ϕ = Phase angle = -55° (Negative i.e. lagging)

iii) $\cos\phi = \cos(-55^\circ) =$ **0.5735 lagging**

iv) $P = VI\cos\phi = 230 \times 18.843 \times 0.5735 =$ **2485.486 W**

v) $V_R = I \times R = 18.843 \times 7 =$ **131.901 V** (magnitude)

$V_L = I \times X_L = 18.843 \times 10 =$ **188.43 V** (magnitude)

Q.17 Find the expression for current when v = 282.84 sin (314 t) V is applied to coil having resistance 10 ohm and inductance 0.1 H. Also calculate the power consumed. ☞ [SPPU : May-16, Marks 7]

Ans. : R = 10 Ω, L = 0.1 H

Compare voltage with $v(t) = V_m \sin(\omega t)$

$\therefore V_m = 282.84$ V i.e. $V = \frac{V_m}{\sqrt{2}} = 200$ V (RMS)

$\therefore \omega = 314$ rad/s i.e. $X_L = \omega L = 31.4 \ \Omega$

$\therefore Z = R + jX_L = 10 + j\,31.4 \ \Omega = 32.954 \angle 72.334^\circ \ \Omega$

$I = \frac{V}{Z} = \frac{200 \angle 0^\circ}{32.954 \angle 72.334^\circ} = 6.069 \angle -72.334^\circ$ A

$\therefore I_m = \sqrt{2} I = \sqrt{2} \times 6.069 = 8.583$ A, $\phi = -72.334^\circ$

$\therefore i(t) = I_m \sin(\omega t + \phi) =$ **8.583 sin (314 t − 72.334°) A**

$P = VI\cos\phi = 200 \times 6.069 \times \cos(-72.334^\circ) =$ **368.35 W**

Q.18 The resistance of 5 Ω is connected across 200 V, 50 Hz 1-phase a.c. supply. The voltage across the resistance is 50 V. Calculate : i) Voltage across inductance ii) Value of inductance iii) Power and iv) Power factor ☞ [SPPU : May-17, Marks 7]

Ans. : The circuit is shown in the Fig. Q.18.1.

$V_R = IR$ i.e. $50 = 5 \times I$

$\therefore I = 10$ A ... Magnitude

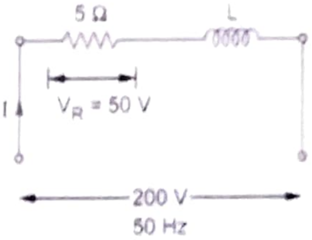


Fig. Q.18.1

$Z = R + jX_L$

and $|I| = \frac{|V|}{|Z|} = \frac{|V|}{\sqrt{R^2 + X_L^2}}$

$\therefore 10 = \frac{200}{\sqrt{5^2 + X_L^2}}$

i.e. $X_L = 19.365 \ \Omega$

i) $V_L = I \times X_L$

$= 10 \times 19.365 =$ **193.65 V** ... Magnitude

ii) $X_L = 2\pi f L$ i.e. $L = \frac{19.365}{2\pi \times 50} =$ **0.0616 H**

iii) $P = |I|^2 R = 10^2 \times 5 =$ **500 W**

... Pure L does not consume power

iv) Power factor $\frac{R}{Z} = \frac{5}{\sqrt{R^2 + X_L^2}} = \frac{5}{\sqrt{5^2 + 19.365^2}} =$ **0.25 lagging**

3.6 : Series R-C Circuit

Q.19 Derive an expression for current drawn and power consumed by a circuit consisting of 'R' and 'C' connected in series across $v = V_m \sin \omega t$ supply. ☞ [SPPU : Dec.-05,10,12, May-06,08,17,18, Marks 6]

Ans. : Consider a circuit consisting of pure resistance R-ohms and connected in series with a pure capacitor of C-farads as shown in the Fig. Q.19.1.

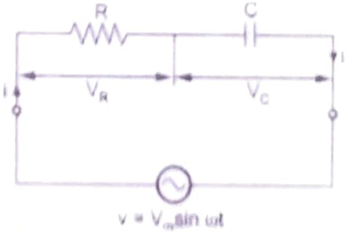


Fig. Q.19.1 Series R-C circuit

- The series combination is connected across a.c. supply given by,

$v = V_m \sin \omega t$

- Circuit draws a current I, then there are two voltage drops,

a) Drop across pure resistance $V_R = I \times R$

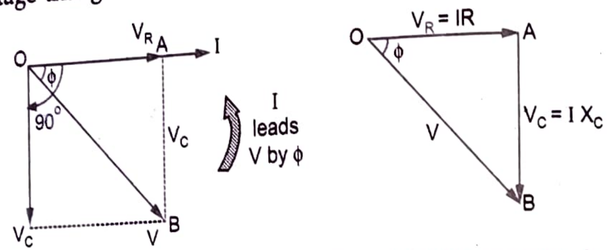
b) Drop across pure capacitance $V_C = I \times X_C$

Where $X_C = \frac{1}{2\pi f C}$ and I, V_R, V_C are the r.m.s. values

- The Kirchhoff's voltage law can be applied to get,

$$V = \overline{V_R} + \overline{V_C} = \overline{IR} + \overline{IX_C} \qquad \text{... (Phasor Addition)}$$

- The phasor diagram is shwon in the Fig. Q.19.2(a) while the voltage triangle is shown in the Fig. Q.19.2(b).



(a) Phasor diagram Fig. Q.19.2 (b) Voltage triangle

- Note that V_R is along the current phasor as for the resistance, voltage and current are in phase. While V_C must be drawn such that current leads V_C by 90°.
- From the voltage triangles,

$$V = \sqrt{(V_R)^2 + (V_C)^2} = \sqrt{(IR)^2 + (I X_C)^2} = I\sqrt{(R)^2 + (X_C)^2} = IZ$$

where $\boxed{Z = \sqrt{(R)^2 + (X_C)^2}}$ is the impedance of the circuit.

- It can be seen that current leads voltage by angle ϕ hence

$$\boxed{v(t) = V_m \sin \omega t \quad \text{and} \quad i(t) = I_m \sin (\omega t + \phi)}$$

- The power is the product of instantaneous values of voltage and current.

$$\therefore P = v \times i = V_m \sin \omega t \times I_m \sin (\omega t + \phi)$$

$$= V_m I_m [\sin (\omega t).\sin (\omega t + \phi)] = V_m I_m \left[\frac{\cos(-\phi) - \cos(2\omega t + \phi)}{2}\right]$$

$$= \frac{V_m I_m \cos\phi}{2} - \frac{V_m I_m}{2} \cos (2\omega t + \phi) \qquad \text{as } \cos(-\phi) = \cos\phi$$

- Now, second term is cosine term whose average value over a cycle is zero. Hence, average power consumed by the circuit is,

$$P_{av} = \frac{V_m I_m}{2} \cos\phi = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos\phi$$

$$\therefore \quad \boxed{P = V I \cos\phi \ \text{watts}} \quad \text{where V and I are r.m.s. values}$$

Q.20 Draw waveforms of voltage, current and instantaneous power for R-C series circuit. State the expressions for voltage, current and power.

Ans. : The voltage and current for series R-C circuit are given by,

$$\boxed{v(t) = V_m \sin \omega t \quad \text{and} \quad i(t) = I_m \sin (\omega t + \phi)}$$

- While the expression for the instantaneous power is given by,

$$P = \frac{V_m I_m \cos\phi}{2} - \frac{V_m I_m}{2} \cos (2\omega t + \phi)$$

- The waveforms for the voltage, current and power for series R-C circuit are shown in the Fig. Q.20.1.

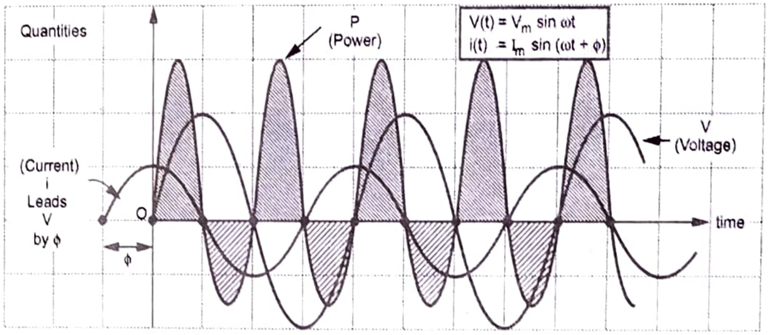


Fig. Q.20.1 Voltage, current and power waveforms for R-C series circuit

Important Points to Remember

- For any single phase a.c. circuit, the average power is given by,

P = V I cos ϕ watts, where **V, I are r.m.s. values, ϕ** is angle between V and I.

Apparent power, $S = V I$ VA

True or average power, $P = V I \cos\phi$ W

Reactive power, $Q = V I \sin\phi$ VAR

$\cos\phi$ = Power factor of circuit

- $\cos\phi$ is **lagging** for **inductive** circuit and $\cos\phi$ is **leading** for **capacitive** circuit.
- For series R-C circuit, $Z = R - jX_C = |Z| \angle -\phi\ \Omega$

$$|Z| = \sqrt{R^2 + X_C^2},\ \phi = \tan^{-1}\left[\frac{-X_C}{R}\right]$$

ϕ is negative for capacitive impedance

Q.21 The series circuit having resistance 5 Ω and capacitance 150 μF is connected to 1-phase, 200 V, 50 Hz AC supply. Calculate - i] capacitive reactance X_C ii] impedance iii] current drawn by the circuit iv] power factor v] active power and vi] reactive power.

☞ [SPPU : May-19, Marks 6]

Ans. : Given : The circuit is shown in the Fig. Q.21.1

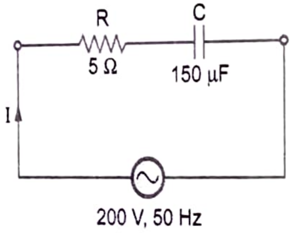


Fig. Q.21.1

To find : X_C, Z, I, $\cos\phi$, P, Q

i) $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 150 \times 10^{-6}} = \mathbf{21.22\ \Omega}$

ii) $Z = R - jX_C = 5 - j\,21.22\ \Omega = 21.801 \angle -\mathbf{76.74°\ \Omega}$

iii) $I = \frac{V}{Z} = \frac{200\angle 0°}{21.801\angle -76.74°} = 9.174 \angle + \mathbf{76.74°\ A}$

---

iv) $\cos\phi = \cos(-76.74°) = \mathbf{0.229\ leading}$

v) $P = V I \cos\phi = 200 \times 9.174 \times 0.229 = \mathbf{420.85\ W}$

vi) $Q = V I \sin\phi = 200 \times 9.174 \times \sin(-76.74)° = \mathbf{-\ 1785.88\ VAR}$

Negative sign indicates leading nature of reactive power.

Q.22 A R-C series circuit is connected across 100 V, 50 Hz supply draws a current of 5 A at a power factor 0.3 leading. Find the value of R and C. Also find power consumed.

☞ [SPPU : Dec.-18, Marks 7]

Ans. : V = 100 V, f = 50 Hz, I = 5 A,

$\cos\phi = 0.3$ leading

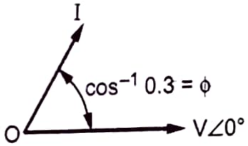


Fig. Q.22.1

$\therefore\quad \phi = \cos^{-1} 0.3 = 72.5424°$ leading

$\therefore\quad I = 5\angle +72.5424°,\ V = 100\angle 0°\ V$

$\therefore\quad Z = \frac{V}{I} = \frac{100\angle 0°}{5\angle +72.5424°}$

$= 20\angle -72.5424°\ \Omega = 6 - j\,19.079\ \Omega = R - jX_C\ \Omega$

$\therefore\quad R = 6\ \Omega,$

$X_C = 19.079 = \frac{1}{2\pi fC}$

$\therefore\quad C = 166.839\ \mu F$

$\therefore\quad P = V I \cos\phi = 100 \times 5 \times 0.3 = \mathbf{150\ W}$

3.7 : Series R-L-C Circuit

Q.23 Sketch and explain the phasor diagram of RLC series circuit for i) $X_C > X_L$ ii) $X_C < X_L$ iii) $X_C = X_L$.

☞ [SPPU : May-04, 10, 13, 15, Dec.-03, 06, Marks 6]

Ans. : Consider a circuit consisting of resistance R ohms pure inductance L henries and capacitance C farads connected in series with each other across a.c. supply. The circuit is shown in the Fig. Q.23.1.

- The a.c. supply is given by, $v = V_m \sin \omega t$.
- The circuit draws a current I.

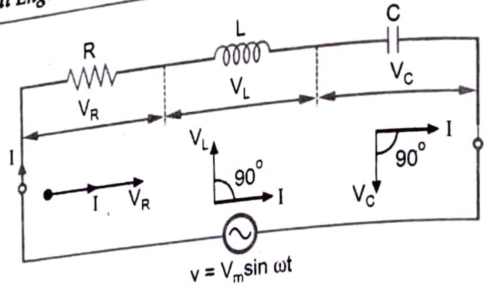


Fig. Q.23.1 R-L-C series circuit

- Due to current I, there are different voltage drops across R, L and C which are given by,

∴

a) Drop across resistance R is $V_R = I\,R$

b) Drop across inductance L is $V_L = I\,X_L$

c) Drop across capacitance C is $V_C = I\,X_C$

- According to Kirchhoff's laws, we can write,

$$\bar{V} = \bar{V}_R + \bar{V}_L + \bar{V}_C \qquad \text{... Phasor addition}$$

Following are the steps to draw the phasor diagram :

1) Take current as reference.

2) V_R is in phase with I.

3) V_L leads current I by 90°.

4) V_C lags current I by 90°.

5) Obtain the resultant of V_L and V_C. Both V_L and V_C are in phase opposition (180° out of phase).

6) Add that with V_R by law of parallelogram to get the supply voltage.

Case 1 : $X_L > X_C$

- When $X_L > X_C$, obviously, I X_L i.e. V_L is greater than I X_C i.e. V_C. So, resultant of V_L and V_C will be directed towards V_L i.e. leading current I.
- The phasor sum of V_R and $(V_L - V_C)$ gives the resultant supply voltage, V. This is shown in the Fig. Q.23.2.

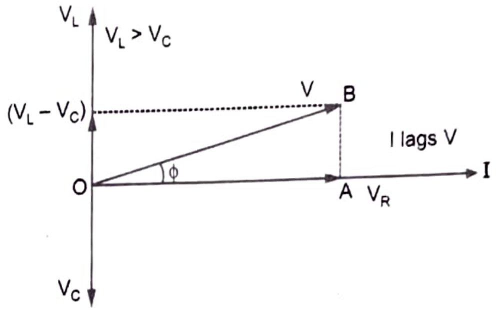


Fig. Q.23.2 Phasor diagram for $X_L > X_C$

- The circuit is inductive in nature and current lags the voltage.

Case 2 : $X_L < X_C$

- When $X_L < X_C$, obviously, I X_L i.e. V_L is less than I X_C i.e. V_C. So, the resultant of V_L and V_C will be directed towards V_C.
- The phasor sum of V_R and $(V_C - V_L)$ gives the resultant supply voltage V. This is shown in the Fig. Q.23.3.

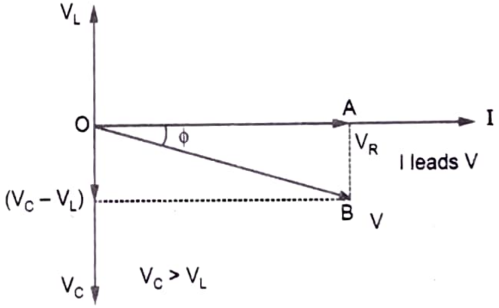


Fig. Q.23.3 Phasor diagram for $X_L < X_C$

- The circuit is capacitive in nature and current leads the voltage.

Case 3 : $X_L = X_C$

- When $X_L = X_C$, obviously, $V_L = V_C$.
- So, V_L and V_C will cancel each other and their resultant is zero.
- Thus $V_R = V$ in such case and overall circuit is purely resistive in nature.

- The phasor diagram is shown in the Fig. Q.23.4.

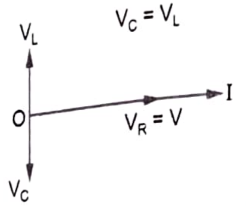


Fig. Q.23.4 Phasor diagram for $X_L = X_C$

Summary of RLC Circuits :

Sr. No.	Circuit	Impedance (Z)		ϕ	p.f. cos ϕ	Remark
		Polar	Rectangular			
1.	Pure R	$R \angle 0° \, \Omega$	$R + j0 \, \Omega$	0°	1	Unity p.f.
2.	Pure L	$X_L \angle 90° \, \Omega$	$0 + j X_L \, \Omega$	90°	0	Zero lagging
3.	Pure C	$X_C \angle -90° \, \Omega$	$0 - j X_C \, \Omega$	– 90°	0	Zero leading
4.	Series RL	$\lvert Z \rvert \angle + \phi° \, \Omega$	$R + j X_L \, \Omega$	$0° \angle \phi \angle 90°$	cos ϕ	Lagging
5.	Series RC	$\lvert Z \rvert \angle - \phi° \, \Omega$	$R - jX_C \, \Omega$	$-90° \angle \phi \angle 0°$	cos ϕ	Leading
6.	Series RLC	$\lvert Z \rvert \angle \pm \phi° \, \Omega$	$R + j X \, \Omega$ $X = X_L - X_C$	ϕ	cos ϕ	$X_L > X_C$ Lagging $X_L < X_C$ Leading $X_L = X_C$ Unity

Q.24 An e.m.f given by v = 100 sin 100 π t is impressed across a circuit consisting of resistance of 40 Ω in series with 100 μF capacitor and 0.25 H inductor. Determine : i) r.m.s value of the current ii) power consumed iii) power factor.

☞ [SPPU : May-14, Marks 6]

Ans. : $V = 100 \sin 100 \pi t = V_m \sin \omega t$

$V_m = 100 \text{ V}, \ \omega = 100 \pi \text{ rad/s}$

$X_L = \omega L = 78.54 \ \Omega$

$X_C = \dfrac{1}{\omega C} = 31.831 \ \Omega$

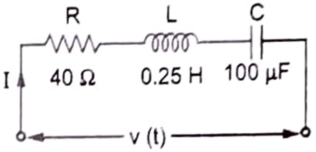


Fig. Q.24.1

$Z = R + j X_L - j X_C$

$= 40 + j \, 46.71 \ \Omega = 61.496 \angle 49.425° \ \Omega$

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 70.7106 \text{ V}$$

i) $I \text{ (RMS)} = \dfrac{V_{rms}}{Z} = \dfrac{70.7106 \angle 0°}{61.496 \angle 49.425°} = \mathbf{1.15 \angle -49.425° \ A}$

ii) $P = V I \cos \phi = 70.7106 \times 1.15 \times \cos(-49.425°) = \mathbf{52.8922 \ W}$

iii) $\cos \phi$ = Power factor = **0.6504 lagging.**

Q.25 An impedance $Z_1 = (100 + j0) \ \Omega$ is connected in series with another impedance $Z_2 = (50 + j80) \ \Omega$. The circuit is connected to a single phase 230 V, 50 Hz supply. Calculate

i) current drawn by the circuit

ii) power consumed by whole circuit

iii) circuit power factor.

☞ [SPPU : May-15, Marks 7]

Ans. : $Z_1 = 100 + j0 \ \Omega = 100 \angle 0° \ \Omega, \ Z_2 = 50 + j80 \ \Omega = 94.34 \angle 58° \ \Omega$

$Z_T = Z_1 + Z_2 = 150 + j80 \ \Omega = 170 \angle 28.072° \ \Omega, V = 230 \angle 0° \text{ V}$

i) $I = \dfrac{V}{Z_T} = \dfrac{230 \angle 0°}{170 \angle 28.072°} = \mathbf{1.353 \angle -28.072° \, A}$ ...current

ii) $\phi = 28.072°, \cos \phi = 0.8823$ lagging

$\therefore$ $P = VI \cos \phi = 230 \times 1.353 \times 0.8823 = \mathbf{274.58 \ W}$

iii) Power factor = $\cos \phi$ = **0.8823** lagging

3.8 : A.C. Parallel Circuit

Important Points to Remember

- A parallel circuit is one in which two or more impedances are connected in parallel across the supply voltage. Each impedance may be a separate series circuit. Each impedance is called branch of the parallel circuit.
- The Fig. 3.1 shows a parallel circuit consisting of three impedances connected in parallel across an a.c. supply of V volts.
- **The voltage across all the impedances is same as supply voltage of V volts.**

Applying Kirchhoff's law,

$$\bar{I} = \bar{I_1} + \bar{I_2} + \bar{I_3} \qquad \text{... (Phasor addition)}$$

$$\therefore \quad \frac{\bar{V}}{\bar{Z}} = \frac{\bar{V}}{\bar{Z_1}} + \frac{\bar{V}}{\bar{Z_2}} + \frac{\bar{V}}{\bar{Z_3}} \quad \text{i.e.} \quad \frac{1}{\bar{Z}} = \frac{1}{\bar{Z_1}} + \frac{1}{\bar{Z_2}} + \frac{1}{\bar{Z_3}}$$

Where Z = **equivalent impedance.**

The steps to solve parallel a.c. circuit :

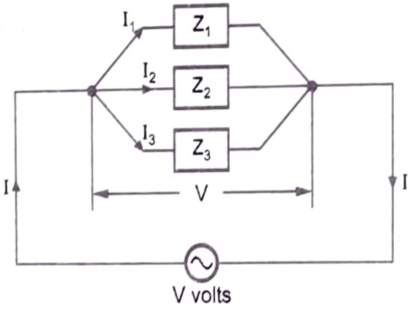


Fig. 3.1 A.C. parallel circuit

1) The currents in the individual branches are to be calculated by using the relation

$$\bar{I_1} = \frac{\bar{V}}{\bar{Z_1}}, \quad \bar{I_2} = \frac{\bar{V}}{\bar{Z_2}}, \ldots\ldots, \quad \bar{I_n} = \frac{\bar{V}}{\bar{Z_n}}$$

---

2) Voltage must be taken as reference phasor as it is common to all branches.
3) Represent all the currents mathematically by expressing them in **rectangular form**. Add them to get the resultant current drawn from the supply.
4) Express the resultant current in the polar form.
5) The phase angle of resultant current I is power factor angle. Cosine of this angle is the power factor of the circuit.

Q.26 What is admittance ? Which are its two components ? State their units. How the admittance is expressed in rectangular and polar form ? **☞[SPPU : Dec.-10, 18, May-10, 12, 15, 16, Marks 5]**

OR Define conductance and susceptance. **☞[SPPU : May-04, 06, 07, 08, 09, Dec.-06, 08, 09, Marks 2]**

Ans. : Admittance is defined as the reciprocal of the impedance. It is denoted by Y and is measured in unit **siemens** or **mho**.

- Consider an impedance given as, $Z = R \pm j X$
- Positive sign for inductive and negative for capacitive circuit.

Admittance $Y = \frac{1}{Z} = \frac{1}{R \pm j X}$

- Rationalising the above expression,

$$Y = \frac{R \mp j X}{(R \pm j X)(R \mp j X)} = \frac{R \mp j X}{R^2 + X^2} = \left(\frac{R}{R^2 + X^2}\right) \mp j \left(\frac{X}{R^2 + X^2}\right)$$

$$= \frac{R}{Z^2} \mp j \frac{X}{Z^2}$$

$$\therefore \quad \boxed{\begin{aligned} Y &= G \mp j B \text{ where } G = \text{Conductance} = \frac{R}{Z^2}, \\ B &= \text{Susceptance} = \frac{X}{Z^2} \end{aligned}}$$

Conductance (G) :

It is defined as the ratio of the resistance to the square of the impedance. It is measured in the unit **siemens.**

Susceptance (B) :

It is defined as the ratio of the reactance to the square of the impedance. It is measured in the unit **siemens.**

The susceptance is said to be inductive (B_L) if its sign is negative. The susceptance is said to be capacitive (B_C) if its sign is positive.

Admittance in polar form is expressed as,

$$Y = G + j\,B = |\,Y\,| \angle \phi \text{ siemens or mh}$$

$$|Y| = \sqrt{G^2 + B^2},\ \phi = \tan^{-1}\frac{B}{G}$$

B is negative if inductive and B is positive if capacitive

Important Points to Remember

- If there are two impedances connected in parallel and if I_T is the total current, then current division rule can be applied to find individual branch currents as,

$$\bar{I}_1 = \bar{I}_T \times \frac{\overline{Z_2}}{\overline{Z_1} + \overline{Z_2}} \quad \text{and} \quad \bar{I}_2 = \bar{I}_T \times \frac{\overline{Z_1}}{\overline{Z_1} + \overline{Z_2}}$$

- The equivalent impedance when two impedances are in parallel is given by,
- $Z = \dfrac{Z_1 \times Z_2}{Z_1 + Z_2}$
- Use rectangular form to perform addition and polar form to perform multiplication and division.

Admittance Method to Solve Parallel Circuit

- The various steps to solve the parallel circuit by admittance method are,

Step 1 : Calculate the admittance of each branch from the respective impedance.

$$Y_1 = \frac{1}{Z_1},\ Y_2 = \frac{1}{Z_2},\ Y_3 = \frac{1}{Z_3} \ \ldots\ldots$$

Step 2 : Convert all the admittances to the respective rectangular form.

Step 3 : Calculate the equivalent admittance of the circuit by adding the individual admittances of the branches.

$$Y_{eq} = Y_1 + Y_2 + Y_3 \ldots\ldots = G_{eq} + B_{eq} = |\,Y\,| \angle \phi$$

Step 4 : The total current drawn from the supply is then given by,

$$I_T = V \times Y_{eq}$$

Step 5 : The individual branch currents can be obtained as,

$$I_1 = V \times Y_1,\quad I_2 = V \times Y_2,\quad I_3 = V \times Y_3 \ \ldots\ldots$$

- It can be crosschecked that the vector addition of all the above currents gives the total current calculated in step 4.

Step 6 : The angle between V and I_T is the power factor angle ϕ. The cosine of this angle is the power factor of the circuit. The power factor of the circuit can also be obtained as,

$$\cos \phi = \frac{G_{eq}}{Y_{eq}}$$

- The nature of the power factor is to be decided from the sign of B_{eq}. If it is negative power factor is lagging while if it is positive the power factor is leading.

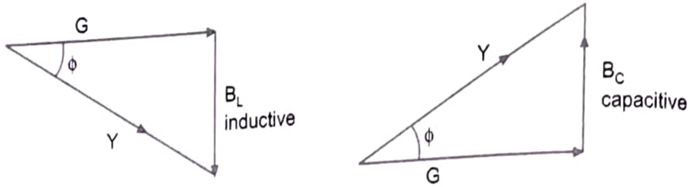
Step 7 : Voltage must be taken as reference phasor as it is common to all branches to draw the phaseor diagram.

Q.27 Draw the admittance triangle and explain.

☞ [SPPU : Dec.-05,13, May-08, 09, Marks 2]

Ans. : The sides of the triangle representing the conductance, susceptance and admittance of the circuit, is known as **admittance triangle.**

- The Fig. Q.27.1 shows such admittance triangles for inductive and capacitive circuits.



(a) Inductive, B_L negative (b) Capacitive, B_C positive

Fig. Q.27.1 Admittance triangles

Q.28 Two circuits having impedances $Z_1 = 8 + j6\ \Omega$ and $Z_2 = 5 + j10\ \Omega$ are connected in parallel across 200 V, 50 Hz, 1-ph a.c. supply. Calculate : i) Current drawn by each circuit ii) Total current iii) p.f. of whole circuit. **☞ [SPPU :Dec.-15, Marks 6]**

Ans. : $Z_1 = 8 + j6\ \Omega$

$= 10 \angle 36.869^\circ\ \Omega$

$Z_2 = 5 + j10\ \Omega$

$= 11.18 \angle 63.435^\circ\ \Omega$

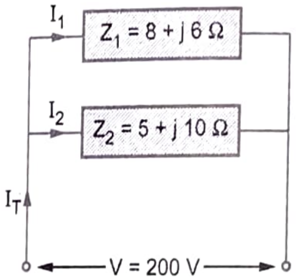


Fig. Q.28.1

Let V = 200 V is reference.

i) $I_1 = \dfrac{V}{Z_1} = \dfrac{200 \angle 0^\circ}{10 \angle 36.869^\circ}$

$= \mathbf{20 \angle -36.869^\circ\ A}$

$= \mathbf{16 - j\ 12\ A}$

$I_2 = \dfrac{V}{Z_2} = \dfrac{200 \angle 0^\circ}{11.18 \angle 63.435} = \mathbf{17.89 \angle -63.435^\circ A = 8 - j\ 16\ \Omega}$

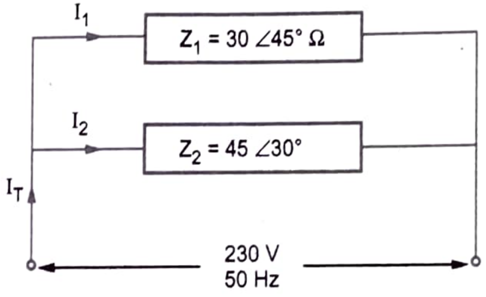
ii) $I_T = \bar{I_1} + \bar{I_2} = 16 - j\ 12 + 8 - j\ 16 = 24 - j\ 28\ A$

$= \mathbf{36.878 \angle -49.398^\circ\ A}$

iii) p.f. of whole circuit = cos (– 49.398º) = **0.6508 lagging**

Q.29 Two impedance $Z_1 = 30 < 45^\circ\ \Omega$ and $Z_2 = 45 < 30^\circ\ \Omega$ are connected in parallel across a single phases 230 V, 50 Hz supply. Calculate the i) current drawn ii) power factor and iii) power consumed by the circuit **☞ [SPPU : May-18, Marks 7]**

Ans. : The circuit is shown in the Fig. Q.29.1.



I_1
$Z_1 = 30 \angle 45^\circ\ \Omega$
I_2
$Z_2 = 45 \angle 30^\circ$
I_T
230 V
50 Hz

Fig. Q.29.1

Let $V = 230 \angle 0^\circ$ V is reference

i) $I_1 = \dfrac{V}{Z_1} = \dfrac{230 \angle 0^\circ}{30 \angle 45^\circ} = \mathbf{7.667 \angle -45^\circ\ A = 5.421 - j5.421\ A}$

$I_2 = \dfrac{V}{Z_2} = \dfrac{230 \angle 0^\circ}{45 \angle 30^\circ} = \mathbf{5.111 \angle -30^\circ\ A = 4.426 - j2.555\ A}$

$\therefore \quad I_T = \bar{I}_1 + \bar{I}_2 = 5.421 - j\,5.421 + 4.426 - j\ 2.555$

$= 9.847 - j\,7.976\ A = \mathbf{12.672 \angle -39^\circ\ A}$

ii) $\cos\phi = \cos(-39^\circ) = \mathbf{0.777\ lagging}$

iii) $P = VI_T \cos\phi = 230 \times 12.672 \times 0.777 = \mathbf{2264.613\ w}$

3.9 : Resonance in Series R-L-C Circuit

Q.30 What is resonance in series circuit ?

☞ [SPPU : Dec.-04, 06, 15, May-16, 17, Marks 2]

Ans. : Both X_L and X_C are the functions of frequency f. When f is varied both X_L and X_C also get varied.

- At a certain frequency, X_L becomes equal to X_C. Such a condition when $X_L = X_C$ for a certain frequency is called **series resonance.**
- The frequency at which the resonance occurs is called **resonant frequency** denoted as ω_r rad/sec or f_r Hz.

Q.31 State the characteristics of series resonance.

Ans. : In a series resonance, the voltage applied is constant and frequency is variable.

- As $X_L = 2\pi fL$, as frequency is changed from 0 to ∞, X_L increases linearily and graph of X_L against f is straight line passing through origin.
- As $X_C = \frac{1}{2\pi fC}$, as frequency is changed from 0 to ∞, X_C reduces and the graph of X_C against f is rectangular hyperbola.

1. At $f = f_r$, the value of $X_L = X_C$ at this frequency.

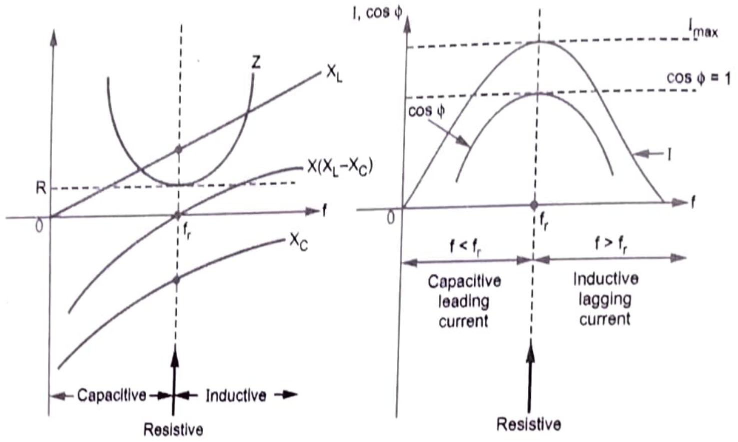


Fig. Q.31.1 Characteristics of series resonance

2. As $X = X_L - X_C$, the graph of X against f is shown in the Fig. Q.31.1.
3. For $f < f_r$, the $X_C > X_L$ and net reactance X is **capacitive** while for $f > f_r$, the $X_L > X_C$ and net reactance X is **inductive.**

4. $Z = R + jX = R + j(X_L - X_C)$ but at $f = f_r$, $X_L = X_C$ and $X = 0$ hence the net impedance $\bar{Z} = R$ which is purely resistive. So **impedance** is **minimum** and **purely resistive** at series resonance.
5. The graph of Z against f is also shown in the Fig. Q.31.1.
6. As impedance is minimum, the **current** $I = V/Z$ is **maximum** at series resonance.
7. The power factor $\cos\phi = R/Z$ and at $f = f_r$ as $Z = R$, the **power factor** is **unity** and at its **maximum** at series resonance. For $f < f_r$ it is **leading** in nature while for $f > f_r$ it is **lagging** in nature.

Q.32 Derive the equation for the resonant frequency in series RLC circuit. Draw the phasor diagram.

[SPPU : Dec.-04,06,09,15, May-02,16,17,19, Marks 3]

Ans. : Let f_r be the resonant frequency in Hz at which,

$$X_L = X_C \quad \text{i.e.} \quad 2\pi f_r L = \frac{1}{2\pi f_r C}$$

... Series resonance

$$\therefore \quad (f_r)^2 = \frac{1}{4\pi^2 LC} \quad \text{i.e.}$$

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hz}}$$

$$\therefore \quad \boxed{\omega_r = 2\pi f_r = \frac{1}{\sqrt{LC}} \text{ rad/sec}}$$

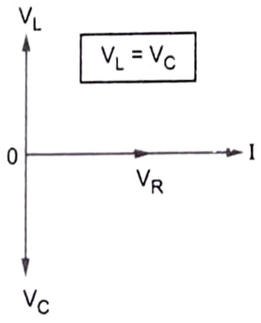


Fig. Q.32.1

The phaser diagram is as shown in the Fig. Q.32.1.

Q.33 A coil of 15 mH is connected in series with 25 Ω resistance and a capacitor across 230 V 50 Hz supply. Find the value of capacitor so that circuit draws maximum current. What will be the power factor and power consumed ? **[SPPU : Dec.-17, Marks 7]**

Ans. : The circuit is shown in the Fig. Q.33.1.

For current to be maximum, the circuit must be in resonance condition i.e. $X_L = X_C$

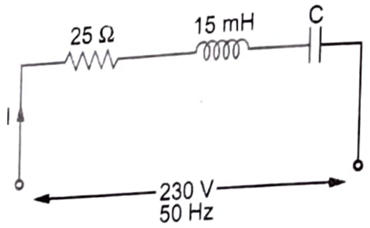


Fig. Q.33.1

$\therefore \quad 2\pi f L = \frac{1}{2\pi f C}$ i.e. $C = \frac{1}{(2\pi \times 50)^2 \times 15 \times 10^{-3}}$

$\therefore \quad C = 675.474\,\mu F$

Power factor = **Unity** ... Resonance

$\therefore \quad P = VI\cos\phi \quad ... \; I = \frac{V}{R} = \frac{230}{25} = 9.2 \text{ A}$

$\therefore \quad P = 230 \times 9.2 \times 1 =$ **2116 W**

Q.34 A coil of inductance 15 mH and resistance 25 Ω resistance is connected in series with a capacitor 'C' across 230 V, 50 Hz supply. Find the value of capacitor so that circuit draws maximum current. What will be the power factor and power consumed ?
☞ [SPPU : Dec.-18, Marks 7]

Ans. : $L = 15$ mH, $R = 25\ \Omega$, $f = 50$ Hz

For maximum current, $Z = R = 25\ \Omega$ and $X_L = X_C$, resonance

$\therefore \quad 2\pi f L = \frac{1}{2\pi f C}$ i.e. $C = \frac{1}{(2\pi \times 50)^2 \times 15 \times 10^{-3}}$

$\therefore \quad C = 675.475\ \mu F$

$\cos\phi = 1$ ... Z = R

$$P = I^2 R = \left(\frac{V}{R}\right)^2 R = \frac{230^2}{25} = 2116 \text{ W}$$

END...✍

UNIT - IV

4 Polyphase A.C. Circuits and Single Phase Transformers

Section A : Polyphase A.C. Circuits

Important Points to Remember

- In a three phase supply system, there are three voltages with a same magnitude and frequency but having a phase difference of 120° between them.
- The equations for the three phase voltages are :

$$e_R = E_m \sin(\omega t)$$

$$e_Y = E_m \sin(\omega t - 120^\circ)$$

$$e_B = E_m \sin(\omega t - 240^\circ) = E_m \sin(\omega t + 120^\circ)$$

- The phasor diagram of these voltages can be shown as in the Fig. 4.1.

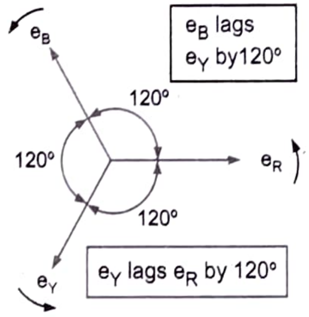


Fig. 4.1 Phasor diagram

- If we add three voltages vectorially, it can be observed that the sum of the three voltages at any instant is zero.

4.1 : Advantages of Three Phase System

Q.1 State the various advantages of three phase system over single phase system. **☞ [SPPU : May-05, Dec.-11, 14, Marks 6]**

Ans. A three phase system has following advantages over single phase system :

1) The output of three phase machine is always greater than single phase machine of same size, approximately 1.5 times. So for a given size and voltage a three phase alternator occupies less space and has less cost too than single phase having same rating.
2) For a transmission and distribution, three phase system needs less copper or less conducting material than single phase system for given volt amperes and voltage rating so transmission becomes very much economical.
3) It is possible to produce rotating magnetic field with stationary coils by using three phase system. Hence three phase motors are self starting.
4) In single phase system, the instantaneous power is a function of time and hence fluctuates w.r.t. time. This fluctuating power causes considerable vibrations in single phase motors. Hence performance of single phase motors is poor. While instantaneous power in symmetrical three phase system is constant.
5) Three phase system give steady output.
6) Single phase supply can be obtained from three phase but three phase cannot be obtained from single phase.
7) Power factor of single phase motor is poor than three phase motors of same rating.
8) For converting machines like rectifiers, the d.c. output voltage becomes smoother if number of phases are increased.

4.2 : Important Definitions Related to Three Phase System

Q.2 Define phase sequence of 3 phase alternating supply. State its significance.

☞[SPPU : May-06,07,08,16, Dec.-04,05,06,09,11, Marks 2]

Ans. : The sequence in which the voltages in three phases reach their maximum positive values is called **phase sequence**. Generally the phase sequence is R-Y-B.

- The phase sequence is important in determining direction of rotation of a.c. motors, parallel operation of alternators etc.
- The phase sequence of a three phase system can be changed by interchanging any two terminals out of R, Y and B.

Q.3 Define symmetrical three phase system.

☞[SPPU : May-07,08, Dec.-06,11, Marks 2]

Ans. : It is possible in polyphase system that magnitudes of different alternating voltages are different.

- But a three phase system in which the three voltages are of same magnitude and frequency and displaced from each other by 120° phase angle is defined as **symmetrical system.**

4.3 : Three Phase Supply Connections

Q.4 Explain the two types of three phase connections.

Ans. : The two types of three phase connections are, 1. Star and 2. Delta

- The star connection is formed by connecting starting or terminating ends of all the three windings together. The ends R_1 - Y_1 - B_1 are connected or ends R_2 - Y_2 - B_2 are connected together. This common point is called **Neutral Point.**
- The remaining three ends are brought out for connection purpose. These ends are generally referred as R-Y-B, to which load is to be connected.
- The star connection is shown in the Fig. Q.4.1.

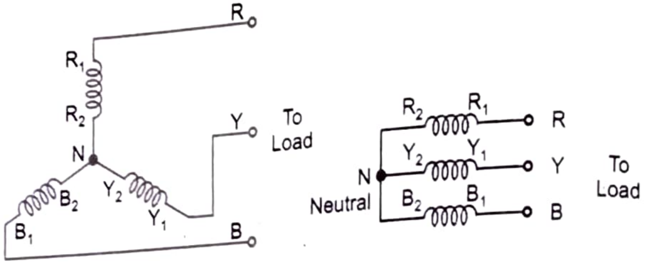


Fig. Q.4.1 Star connection

- The delta is formed by connecting one end of winding to starting end of other and connections are continued to form a closed loop.
- The supply terminals are taken out from the three junction points. Delta connection always forms a closed loop.
- The delta connection is shown in the Fig. Q.4.2.

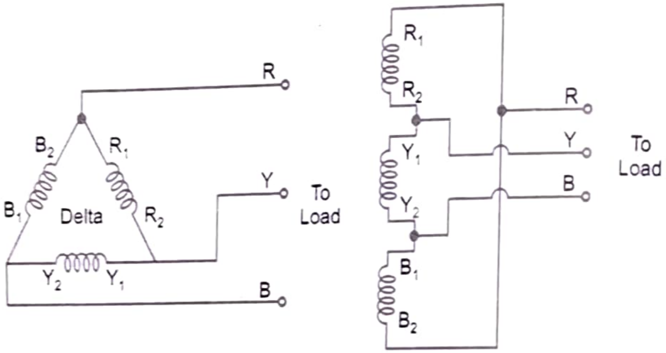


Fig. Q.4.2 Delta connection

4.4 : Balanced and Unbalanced Load

Q.5 Define balanced and unbalanced load.

☞ [SPPU : May-06,07,08,16, Dec.-04,05,06,09,11, Marks 2]

Ans. : **1. Balanced load :** The load is said to be balanced when **magnitude** of all the impedances Z_{ph1}, Z_{ph2} and Z_{ph3} are equal and the **phase angles** of all of them are **equal** and of **same nature** either all inductive or all capacitive or all resistive.

- In case of balanced loads, all phase voltages have equal magnitude and are displaced from each other by 120° while all phase currents also have equal magnitude and are displaced from each other by 120°.

2. Unbalanced load : The load is said to be unbalanced when **magnitude** of all the impedances Z_{ph1}, Z_{ph2} and Z_{ph3} are **unequal** and the **phase angles** of all of them are **unequal and their nature is also different.**

- In case of unbalanced loads, the phase voltages are unequal and not displaced from each other by 120°. The phase currents are also unequal and not displaced from each other by 120°.

Important Points to Remember

- The potential difference between any two lines of supply is called **line voltage** and current passing through any line is called **line current.**
- Line voltages are denoted by V_L which are V_{RY}, V_{YB} and V_{BR} while line currents are denoted as I_L which are I_R, I_Y and I_B.
- The voltage across any branch of the three phase load i.e. across Z_{ph1}, Z_{ph2} or Z_{ph3} is called **phase voltage** and current passing through any branch of the three phase load is called **phase current.**
- The phase voltages are denoted as V_{ph} while the phase currents are denoted as I_{ph}.
- In star connection,
  $V_{ph} = V_R = V_Y = V_B$ while $I_{ph} = I_R = I_Y = I_B = I_L$.

4.5 : Relations for Star Connected Load

Q.6 Derive the relation between line and phase values of currents and voltages for balanced three phase star connected load connected across three phase a.c. supply. Derive also power consumed by the load.

☞[SPPU : Dec.-03,08,16,18, May-08,11,12,14,18, Marks 6]

OR

Q.6 Draw a connection diagram for three phase star connected load connected across three phase a.c. supply.

[SPPU : May-05, Dec.-11, Marks 4]

Ans. : Consider the balanced star connected load as shown in the Fig. Q.6.1.

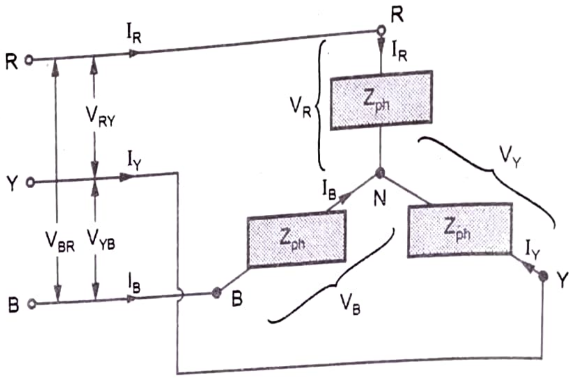


Fig. Q.6.1 Star connected load

- Line voltages,
  $V_L = V_{RY} = V_{YB} = V_{BR}$ and Line currents, $I_L = I_R = I_Y = I_B$
- Phase voltages, $V_{ph} = V_R = V_Y = V_B$ and
  Phase currents, $I_{ph} = I_R = I_Y = I_B$
- It can be seen that the line currents are same as the phase currents i.e. $I_L = I_{ph}$.
- From the Fig. Q.6.1 we can write,

$$\bar{V}_{RY} = \bar{V}_{RN} + \bar{V}_{NY} \quad \text{But} \quad \bar{V}_{NY} = -\bar{V}_{YN}$$

(Generally suffix N is not used for phase voltages)

Hence $\boxed{\bar{V}_{RY} = \bar{V}_R - \bar{V}_Y}$ ...(Q.6.1)

Similarly, $\bar{V}_{YB} = \bar{V}_{YN} + \bar{V}_{NB} = \bar{V}_{YN} - \bar{V}_{BN} = \bar{V}_Y - \bar{V}_B$ ...(Q.6.2)

and $\bar{V}_{BR} = \bar{V}_B - \bar{V}_R$ ...(Q.6.3)

- The three phase voltage are displaced by 120° from each other.

- The phasor diagram to get V_{RY} is shown in the Fig. Q.6.2. The V_Y is reversed to get $-V_Y$ and then it is added to V_R to get V_{RY}.
- The perpendicular is drawn from point A on vector OB representing V_L.
- In triangle OAB, the sides OA and AB are same as phase voltages. Hence OB bisects angle between V_R and $-V_Y$.

$\therefore \quad \angle BOA = 30°$

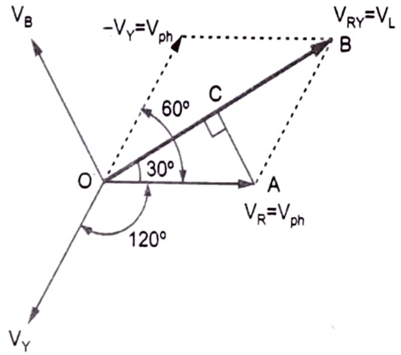


Fig. Q.6.2

- And perpendicular AC bisects the vector OB hence $OC = CB = \frac{V_L}{2}$
- From triangle OAB,
- $\cos 30° = \frac{OC}{OA} = \frac{(V_{RY}/2)}{V_R}$ i.e. $\frac{\sqrt{3}}{2} = \frac{(V_L/2)}{V_{ph}}$

$V_L = \sqrt{3}\, V_{ph}$ for star connection and $I_L = I_{ph}$

Thus line voltage is $\sqrt{3}$ times the phase voltage in star connection.

- The lagging or leading nature of current depends on per phase impedance.

Power : The power consumed in each phase is single phase power given by,

$$P_{ph} = V_{ph} I_{ph} \cos\phi$$

- For balanced load, all phase powers are equal.
- Hence total three phase power consumed is,

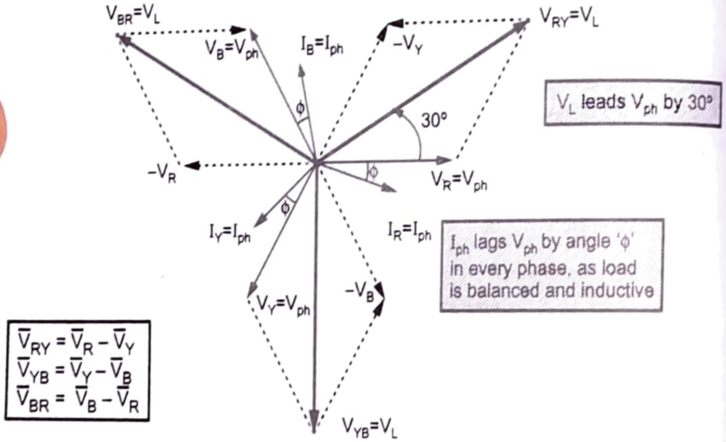
$$P = 3P_{ph} = 3V_{ph} I_{ph} \cos\phi = 3\frac{V_L}{\sqrt{3}} I_L \cos\phi$$

$$\therefore \quad \boxed{P = \sqrt{3}\, V_L I_L \cos\phi \text{ watts}}$$

Q.7 Draw a complete phasor diagram for three phase star connected inductive load connected across three phase a.c. supply.

☞[SPPU : May-09,18, Marks 6]

Ans. : The complete phasor diagram for lagging power factor star connected load is shown in the Fig. Q.7.1.



V_L leads V_{ph} by 30°

I_{ph} lags V_{ph} by angle 'φ' in every phase, as load is balanced and inductive

$$\bar{V}_{RY} = \bar{V}_R - \bar{V}_Y$$
$$\bar{V}_{YB} = \bar{V}_Y - \bar{V}_B$$
$$\bar{V}_{BR} = \bar{V}_B - \bar{V}_R$$

Fig. Q.7.1 Star and lagging p.f. load

- Each I_{ph} lags respective V_{ph} by angle ϕ

4.6 : Relations for Delta Connected Load

Q.8 Derive the relation between line and phase values of currents and voltages for balanced three phase star connected load connected across three phase a.c. supply. Derive also power consumed by the load.

☞[SPPU : Dec.-05,07,12,17, May-04, 05, 07, 08,10,13,17,19, Marks 6]

Ans. : Consider the balanced delta connected load as shown in the Fig. Q.8.1.

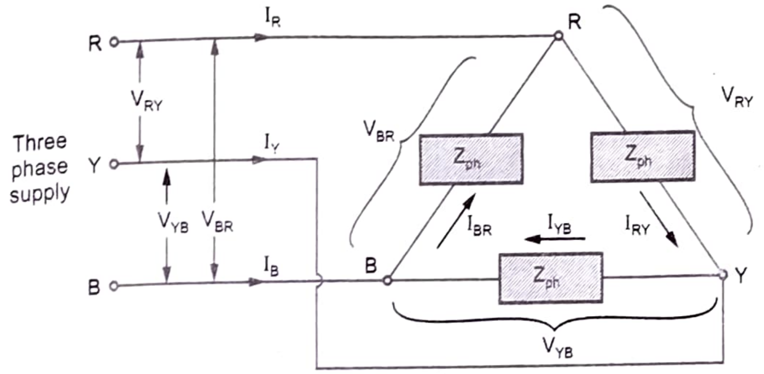


Fig. Q.8.1 Delta connected load

- Line voltages : $V_L = V_{RY} = V_{YB} = V_{BR}$ and

  Line currents : $I_L = I_R = I_Y = I_B$
- Phase voltages : $V_{ph} = V_{RY} = V_{YB} = V_{BR}$ and

  Phase currents : $I_{ph} = I_{RY} = I_{YB} = I_{BR}$
- It can be seen that the line voltages are same as the phase voltages i.e. $V_L = V_{ph}$.
- To derive the relation between I_L and I_{ph}, apply the KCL at the node R of the load shown in the Fig. Q.8.1.

$$\sum I_{entering} = \sum I_{leaving} \text{ at node R}$$

$$\therefore \quad \bar{I}_R + \bar{I}_{BR} = \bar{I}_{RY} \quad \text{i.e.} \quad \bar{I}_R = \bar{I}_{RY} - \bar{I}_{BR} \qquad \ldots(Q.8.1)$$

Applying KCL at node Y and B, we can write equations for line currents I_Y and I_B as,

$$\bar{I}_Y = \bar{I}_{YB} - \bar{I}_{RY} \qquad ...(Q.8.2)$$

$$\bar{I}_B = \bar{I}_{BR} - \bar{I}_{YB} \qquad ...(Q.8.3)$$

- The phasor diagram to obtain line current I_R by carrying out vector subtraction of phase currents I_{RY} and I_{YB} is shown in the Fig. Q.8.2.
- The three phase currents are displaced from each other by 120°.
- I_{BR} is reversed to get $-I_{BR}$ and then added to I_{RY} to get I_R.

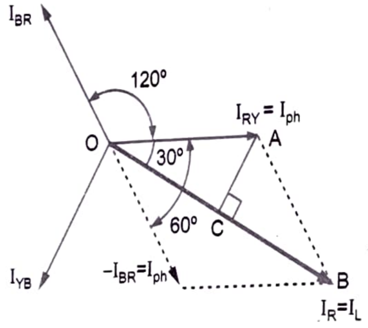


Fig. Q.8.2

- The perpendicular AC drawn on vector OB, bisects the vector OB which represents I_L.
- Similarly OB bisects angle between $-I_{BR}$ and I_{RY} which is 60°.

$$\therefore \quad \angle BOA = 30° \quad \text{and} \quad OC = CB = \frac{I_L}{2}$$

- From triangle OAB, $\cos 30° = \frac{OC}{OA} = \frac{I_R/2}{I_{RY}}$ i.e. $\frac{\sqrt{3}}{2} = \frac{I_L/2}{I_{ph}}$

$I_L = \sqrt{3}\ I_{ph}$ and $V_{ph} = V_L$ ... for delta connection

∴ **Thus line current is $\sqrt{3}$ times the phase current in delta connection.**

- Power consumed in each phase is single phase power given by,

$$P_{ph} = V_{ph}\ I_{ph}\ \cos\phi$$

- Total power $P = 3 P_{ph} = 3 V_{ph} I_{ph} \cos\phi = 3 V_L \frac{I_L}{\sqrt{3}} \cos\phi$

$$\therefore \quad \boxed{P = \sqrt{3}\ V_L I_L \cos\phi \quad \text{watts}}$$

Q.9 Draw a complete phasor diagram for three phase delta connected inductive load connected across three phase a.c. supply.

☞ [SPPU : May-03, Dec.-10, Marks 6]

Ans. : The complete phasor diagram for lagging power factor delta connected load is shown in the Fig. Q.9.1.

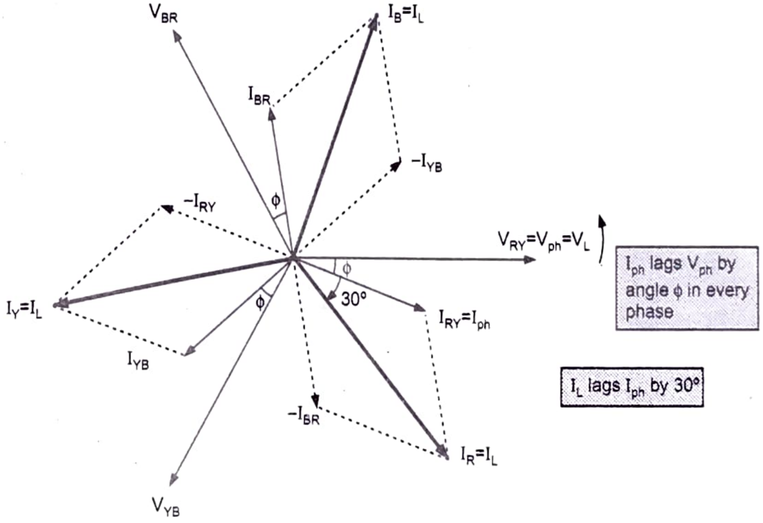


Fig. Q.9.1

For delta connection, to draw phasor diagram use

$$\bar{I}_R = \bar{I}_{RY} - \bar{I}_{BR}, \quad \bar{I}_Y = \bar{I}_{YB} - \bar{I}_{RY} \quad \text{and} \quad \bar{I}_B = \bar{I}_{BR} - \bar{I}_{YB}$$

- Each I_{ph} lags respective V_{ph} by angle φ.

4.7 : Power Triangle for Three Phase Load

Q.10 State the equations for real power, apparent power and reactive power for three phase balanced load. Draw the power triangle. **☞[SPPU : May-09, Marks 3]**

Ans. : The equations for the real power, apparent power and reactive power are,

Total apparent power, $S = \sqrt{3}\, V_L I_L$ volt-amperes (VA) or kVA

Total active or real power, $P = \sqrt{3}\, V_L I_L \cos\phi$ watts (W) or kW

Total reactive power, $Q = \sqrt{3}\, V_L I_L \sin\phi$ reactive volt amperes (VAR) or kVAR

The power triangle is as shown in the Fig. Q.10.1.

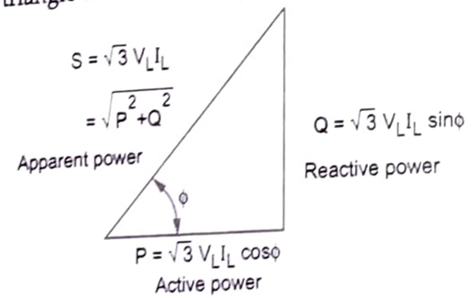


Fig. Q.10.1 Power triangle

While solving three phase problems :

1) Given supply voltages are always line voltages.
2) Determine phase voltage depending on whether load is star or delta connected.
3) Then determine phase current, $I_{ph} = \frac{V_{ph}}{Z_{ph}}$. Use polar forms.
4) Determine line current depending on whether load is star or delta connected.
5) ϕ is angle between V_{ph} and I_{ph}. Value of ϕ can be obtained from given Z_{ph}.
6) The total power consumed is $\sqrt{3}\, V_L I_L \cos\phi$.

Q.11 A delta connected balanced load across a 400 V 3-phase supply consist of three identical impedances, each equal to $(15 + j12)\,\Omega$. Find the line current, active power and reactive power. **☞[SPPU : May-15, Marks 6]**

Ans : $V_L = 400\,\text{V},\ Z_{ph} = 15 + j12\ \Omega = 19.2093\angle 38.66^\circ\ \Omega$

For delta connected, $V_{ph} = V_L = 400$ V

$$\therefore \quad I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{400}{19.2093} = 20.8232\text{A} \quad \text{... Magnitude}$$

$$\therefore \quad I_L = \sqrt{3}\ I_{ph} = \sqrt{3} \times 20.8232 = \mathbf{36.0669\ A} \quad \text{...Magnitude}$$

$$\phi = 38.66^\circ \text{ hence } \cos\phi = 0.7808$$

$$\therefore \quad \text{Active power } P = \sqrt{3}\, V_L\, I_L \cos\phi = \mathbf{19.5105\ kW}$$

$$\text{Reactive power } Q = \sqrt{3}\, V_L\, I_L \sin\phi = \mathbf{15.609\ kVAR}$$

Q.12 Three identical impedances each of 6 + j8 Ω are connected in star across 3-ph, 400 V, 50 Hz a.c. supply. Calculate : i) Line current ii) Active power iii) Reactive power **☞ [SPPU : Dec. - 15, Marks 7]**

Ans. : $Z_{ph} = 6 + j8\ \Omega = 10 \angle 53.13^\circ\ \Omega,\ V_L = 400$ V

$$V_{ph} = \frac{V_L}{\sqrt{3}} = 230.94 \text{ V (star connection)}$$

$$\therefore \quad I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{230.94\angle 0^\circ}{10\angle 53.13^\circ} = 23.094 \angle -53.13^\circ \text{ A}$$

i) $I_L = I_{ph} = \mathbf{23.094\ A}$ (magnitude)

ii) $P = \sqrt{3}\ V_L\ I_L \cos\phi$

$= \sqrt{3} \times 400 \times 23.094 \times \cos(53.13^\circ) = \mathbf{9.6\ kW}$

iii) $Q = \sqrt{3}\ V_L\ I_L \sin\phi = \sqrt{3} \times 400 \times 23.094 \times \sin(53.13^\circ)$

$= \mathbf{12.8\ kVAR}$

Q.13 Three identical impedances each of 6 + j8 Ω are connected in delta across 3-ph, 400 V, 50 Hz ac supply. Calculate : i) Line current ii) Power factor iii) Active power iv) Reactive power **☞ [SPPU : May-16, Marks 7]**

Ans. : $Z_{ph} = 6 + j8\ \Omega = 10 \angle 53.13^\circ\ \Omega,\ V_L = 400$ V

$V_{ph} = V_L = 400$ V (delta) and assume reference

i) $$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{400\angle 0^\circ}{10\angle 53.13^\circ} = 40\angle -53.13^\circ \text{ A}$$

∴ $I_L = \sqrt{3}\, I_{ph} = \sqrt{3} \times 40 = \mathbf{69.282\ A}$ ... magnitude

ii) $\text{P. F.} = \cos\phi = \cos(-53.13^\circ) = \mathbf{0.6\ lagging}$

iii) $P = \sqrt{3}\, V_L\, I_L \cos\phi = \sqrt{3} \times 400 \times 69.282 \times 0.6 = \mathbf{28.8\ kW}$

iv) $Q = \sqrt{3}\, V_L\, I_L \sin\phi = \sqrt{3} \times 400 \times 69.282 \times 0.8 = \mathbf{38.4\ kVAR}$

Q.14 Three coils, each having a resistance of 20 Ω and an inductance of 15 Ω are connected in star to a 400 V, 3-phase, 50 Hz supply. Calculate : i) The line current ii) Power factor and iii) Power supplied. ☞ **[SPPU : Dec.-16, Marks 6]**

Ans. : $Z_{ph} = R_{ph} + j\,X_{Lph} = 20 + j15\ \Omega = 25\angle 36.869^\circ\ \Omega$

$V_L = 400$ V, star, $V_{ph} = \frac{V_L}{\sqrt{3}} = 230.94$ V

i) $$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{230.94\angle 0^\circ}{25\angle 36.869^\circ} = 9.2376\angle -36.869^\circ \text{A}$$

∴ I_L (Magnitude) = I_{ph} (magnitude) = **9.2376 A**

ii) $\cos\phi = \cos(-36.869^\circ) = \mathbf{0.8\ lagging}$

iii) $P = \sqrt{3}\, V_L I_L \cos\phi = \sqrt{3} \times 400 \times 9.2376 \times 0.8 = \mathbf{5120\ W}$

Q.15 A delta connected load draws a line current of 15 ampere at a lagging power factor of 0.85 from a 400 V 50 Hz, 3 phase supply. Find the resistance and inductance of each phase. If the same load is now connected in star, calculate the line current and total power consumed. ☞ **[SPPU : Dec.-17, Marks 7]**

Ans. : Delta, $I_L = 15$ A,

$\cos\phi = 0.85$ lag,

$V_L = 400$ V

∴ $I_{ph} = \frac{I_L}{\sqrt{3}} = \frac{15}{\sqrt{3}} = 8.66$ A(magnitude)

$V_{ph} = V_L = 400$ V ...Delta

∴ $I_{ph} = |I_{ph}| \angle -\cos^{-1}\phi = 8.66\angle -31.788^\circ$ A

∴ $$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{400\angle 0^\circ}{8.66\angle -31.788^\circ} = 46.189\angle +31.788^\circ\ \Omega$$

$= 39.26 + j\,24.231\ \Omega = R_{ph} + j\,X_{Lph}$

∴ $R_{ph} = \mathbf{39.26\ \Omega/ph,}$

$X_{Lph} = 2\pi f L_{ph}$

∴ $L_{ph} = \frac{24.331}{2\pi \times 50} = \mathbf{0.0775\ H/ph}$

For star, $V_{ph} = \frac{V_L}{\sqrt{3}} = 230.94$ V

∴ $I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{230.94}{46.189} = 5$A (magnitude)

∴ $I_L = I_{ph} = 5$A ...Star

∴ $P = \sqrt{3}\, V_L I_L \cos\phi = \sqrt{3} \times 400 \times 5 \times 0.85 = \mathbf{2.945\ kW}$

Q.16 Each phase of star connected load has an impedance (25 + j40) connected across 3-phase, 415 V, 50 Hz supply. Determine.

a) Line current

b) Active, Reactive and Apparent Power

☞ **[SPPU : May-18, Marks 7]**

Ans. : $Z_{ph} = 25 + j40\,\Omega = 47.17\angle 58^\circ\ \Omega$, $V_L = 415$ V

For star, $V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{415}{\sqrt{3}} = 239.6$ V

∴ $I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{239.6}{47.17} = 5.079$ A (magnitude)

a) $I_L = I_{ph} = \mathbf{5.079\ A}$

b) $\phi = 58^\circ$, $\cos\phi = 0.53$, $\sin\phi = 0.848$

∴ $P = \sqrt{3}\, V_L I_L \cos\phi = \mathbf{1934.92\ W}$ ...Active

∴ $Q = \sqrt{3}\, V_L I_L \sin\phi = \mathbf{3095.87\ VAR}$ ...Reactive

$S = \sqrt{3}\, V_L I_L = \mathbf{3650.79\ VA}$ ...Apparent

Section B : Single Phase Transformers

4.8 : Definition of Transformer

Q.17 Define transformer and state its use.

Ans. : The transformer is a static piece of apparatus by means of which an electrical power is transformed from one alternating current circuit to another with the desired change in voltage and current, without any change in the frequency.

- Its use is to raise or lower the alternating voltages as per the requirements in the different stages of electrical network as generation, transmission, distribution and utilization.

4.9 : Working Principle of Transformer

Q.18 Explain the working principle of transformer.
☞[SPPU : May-10, Dec.-10, Marks 4]

Ans. : The transformer works on the principle of **mutual induction which states that when two coils are inductively coupled and if current in one coil is changed uniformly then an e.m.f. gets induced in the other coil.**

- In its elementary form, it consists of two inductive coils which are electrically separated but linked through a common magnetic circuit. The two coils have high mutual inductance. The basic transformer is shown in the Fig. Q.18.1.
- The coil to which supply is given is called primary winding having N_1 number of turns and the other winding connected to the load is called secondary winding having N_2 number of turns.
- When primary winding is excited by an alternating voltage, it circulates an alternating current.
- This current produces an alternating flux (ϕ) which completes its path through common magnetic core as shown dotted in the Fig. Q.18.1. Thus an alternating flux links with the secondary winding.

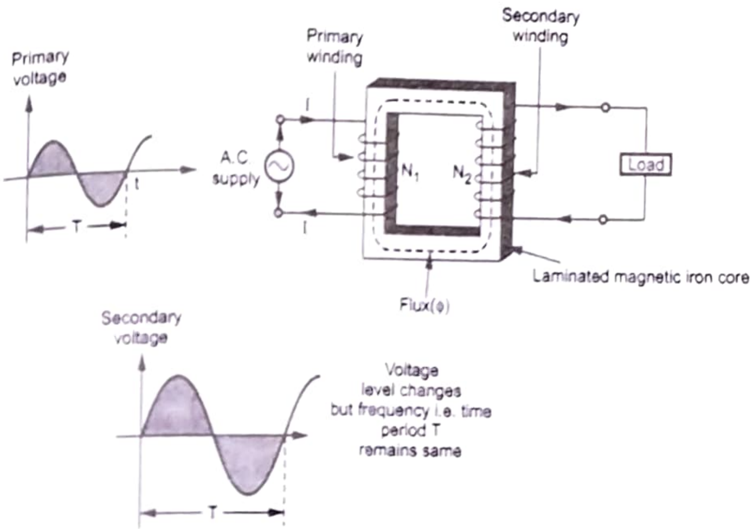

Primary voltage
Primary winding
Secondary winding
I
A.C supply
N1
N2
Load
t
T
Laminated magnetic iron core
Flux(ϕ)
Secondary voltage
Voltage level changes but frequency i.e. time period T remains same
T

Fig. Q. 18.1 Basic transformer

- As the flux is alternating, according to Faraday's law of an electromagnetic induction, mutually induced e.m.f. gets developed in the secondary winding.
- This secondary induced e.m.f. drives the load.
- Thus though there is no electrical contact between the two windings, an electrical energy gets transferred from primary to the secondary.

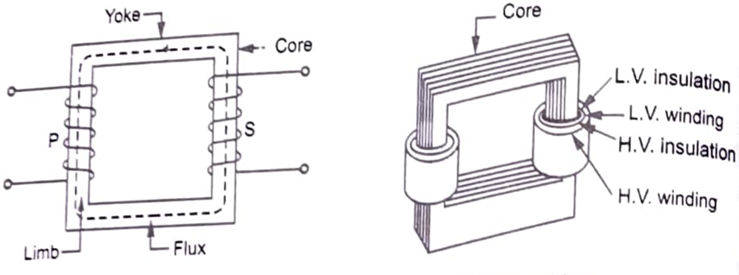
4.10 : Construction of Transformers

Q.19 Draw the neat sketchs to show the constructional of core and shell type transformers. **☞ [SPPU : May-14, Marks 4]**

Ans. : 1. Core type transformer :

- It has a single magnetic circuit. The core is rectangular having two limbs. The winding encircles the core.

- The Fig. Q.19.1 (a) shows the schematic representation of the core type transformer while the Fig. Q.19.1 (b) shows the view of actual construction of the core type transformer.



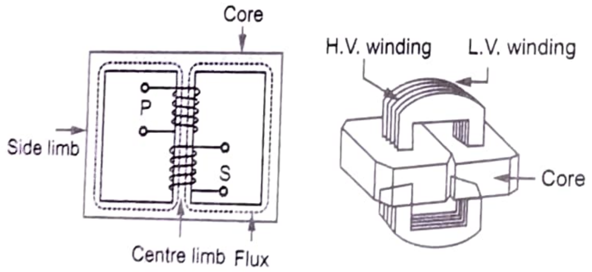
(a) Representation (b) Construction

Fig. Q.19.1 Core type transformer

- Both the coils are placed on both the limbs. The low voltage coil is placed inside near the core while high voltage coil surrounds the low voltage coil.

2. Shell type transformer :

- It has a double magnetic circuit. The core has three limbs.
- Both the windings are placed on the central limb. The core encircles most part of the windings.
- The Fig. Q.19.2(a) shows the schematic representation while the Fig. Q.19.2(b) shows the actual construction of the shell type transformer.



(a) Representation (b) Construction

Fig. Q.19.2 Shell type transformer

Q.20 Compare core type and shell type transformers.
☞ [SPPU : May-06,10,12, Dec.-04,11,13, Marks 6]

Ans. :

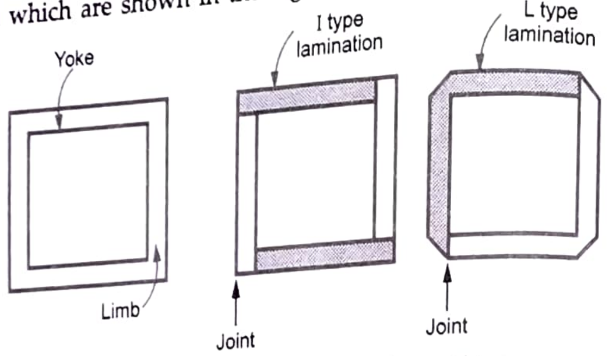
Sr. No.	Core type	Shell type
1.	The winding encircles the core.	The core encircles most part of the windings.
2.	The cylindrical type of coils are used.	Generally, multilayer disc type or sandwich coils are used.
3.	As windings are distributed, the natural cooling is more effective.	As windings are surrounded by the core, the natural cooling does not exist.
4.	The coils can be easily removed from maintenance point of view.	For removing any winding for the maintenance, large number of laminations are required to be removed. This is difficult.
5.	The construction is preferred for low voltage transformers.	The construction is used for very high voltage transformers.
6.	It has a single magnetic circuit.	It has a double magnetic circuit.
7.	In a single phase type, the core has two limbs.	In a single phase type, the core has three limbs.

Q.21 With neat sketches, explain the various types of lamination used for the construction of core of single phase transformer.
☞ [SPPU : Dec.-18, Marks 6]

Ans. : The core of the transformer is either square or rectangular in size.

- Core is made up of laminations. Because of laminated type of construction, eddy current losses get minimized.
- Generally, high grade silicon steel laminations [0.3 to 0.5 mm thick] are used. These laminations are insulated from each other by using insulation like varnish.

- Laminations are overlapped so that to avoid the air gap at th joints. For this generally 'L' shaped or 'I' shaped laminations ar used which are shown in the Fig. Q.21.1.



(a) Core (b) Types of laminations

Fig. Q.21.1

- To avoid high reluctance at the joints, the alternate layers are stacked differently to eliminate the joints. This is called staggering.
- The cross - section of the limb depends on the type of coil to be used either circular or rectangular.

4.11 : E.M.F. Equation of a Transformer

Q.22 Derive the e.m.f. equation of a transformer.

☞ [SPPU : May-04,10,12,13,15,19, Dec.-04,05,06,07,08,09,10,11, Marks 6]

Ans. : When the primary winding is excited by an alternating voltage V_1, it circulates alternating current, producing an alternating flux ϕ.

- The maximum value of this flux is ϕ_m as shown in the Fig. Q.22.1.
- The alternating flux ϕ linking with the primary winding itself induces an e.m.f. in it denoted as E_1.

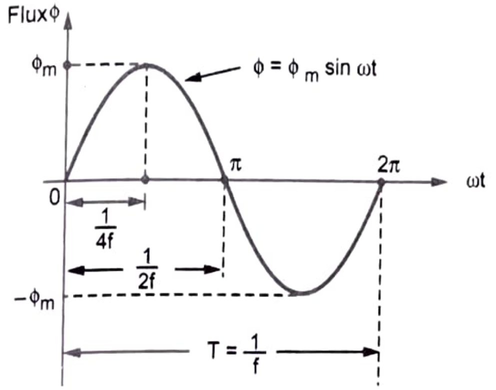


Fig. Q.22.1 Sinusoidal flux

- The flux links with secondary winding through the common magnetic core. It produces induced e.m.f. E_2 in the secondary winding. This is mutually induced e.m.f.
- The various quantities which affect the magnitude of the induced e.m.f. are :

ϕ = Flux and ϕ_m = Maximum value of flux

N_1 = Number of primary winding turns

N_2 = Number of secondary winding turns

f = Frequency of the supply voltage

E_1 = R.M.S. value of the primary induced e.m.f.

E_2 = R.M.S. value of the secondary induced e.m.f.

- From Faraday's law of electromagnetic induction the average e.m.f. induced in each turn is proportional to the average rate of change of flux.

$\therefore$ Average e.m.f. per turn = Average rate of change of flux = $\frac{d\phi}{dt}$

Now, $$\frac{d\phi}{dt} = \frac{\text{Change in flux}}{\text{Time required for change in flux}}$$

- Consider the 1/4th cycle of the flux as shown in the Fig. Q.22.1. Complete cycle gets completed in 1/f seconds. In 1/4th time period, the change in flux is from 0 to ϕ_m.

$$\therefore \quad \frac{d\phi}{dt} = \frac{\phi_m - 0}{\left(\frac{1}{4f}\right)} = 4 f \phi_m \text{ Wb/sec}$$

... as dt for 1/4th time period is 1/4f seconds

∴ **Average e.m.f. per turn** $= 4 f \phi_m$ volts

- For sinusoidal quantity, Form Factor $= \frac{\text{R.M.S. value}}{\text{Average value}} = 1.11$

∴ R.M.S. value = 1.11 × Average value

∴ R.M.S. value of induced e.m.f. per turn $= 1.11 \times 4 f \phi_m = 4.44 f \phi_m$

- There are N_1 number of primary turns hence the R.M.S. value of induced e.m.f. of primary denoted as

  E_1 is $E_1 = N_1 \times 4.44 f \phi_m$ volts

- While as there are N_2 number of secondary turns the R.M.S. value of induced e.m.f. of secondary denoted E_2 is

  $E_2 = N_2 \times 4.44 f \phi_m$ volts

- The expressions of E_1 and E_2 are called e.m.f. equations of a transformer.

$$\boxed{\begin{aligned} E_1 &= 4.44 f \phi_m N_1 \quad \text{volts and} \\ E_2 &= 4.44 f \phi_m N_2 \quad \text{volts} \end{aligned}}$$

Important Points to Remember

- The ratio of secondary induced e.m.f. to primary induced e.m.f. is known as **voltage transformation ratio** denoted as K.

Thus, $\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$ and $E_2 = K E_1$

- **The currents are in the inverse ratio of the voltage transformation ratio** as the product of primary voltage V_1 and primary current I_1, is same as the product of secondary voltage V_2 and the secondary current I_2. Thus $V_1 I_1 = V_2 I_2$.

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = K = \frac{N_2}{N_1}$$

- On both sides primary and secondary VA rating remains same. This rating is generally expressed in kVA (kilo volt amperes rating).

kVA rating of a transformer $= \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}$ ...1000 to express in kVA

- The full load primary and secondary currents indicate the safe maximum values of currents which transformer windings can carry. The full load currents can be obtained from the kVA rating as,

$$I_1 \text{ full load} = \frac{\text{kVA rating} \times 1000}{V_1} \quad \text{...(1000 to convert kVA to VA)}$$

$$I_2 \text{ full load} = \frac{\text{kVA rating} \times 1000}{V_2}$$

Q.23 A single phase 4 kVA transformer has 400 turns on its primary and 1000 secondary turns. The net cross-sectional area of the core is 60 cm². When the primary winding is connected to 500 V, 50 Hz supply. Calculate :

i) the max. value of flux density in the core.

ii) the voltage induced in the secondary winding and

iii) the secondary full load current. ☞ **[SPPU : May-15, Marks 6]**

Ans. : 4 kVA, $N_1 = 400$, $N_2 = 1000$, $a = 60 \text{ cm}^2$, $V_1 = 500$ V

i) $V_1 = 4.44 f \phi_m N_1$ ... f = 50 Hz

∴ $500 = 4.44 \times 50 \times \phi_m \times 400$ i.e. $\phi_m = 5.6306$ mWb

∴ $B_m = \frac{\phi_m}{a} = \frac{5.6306 \times 10^{-3}}{60 \times 10^{-4}} = \mathbf{0.9384 \ Wb/m^2}$

ii) $\frac{V_1}{V_2} = \frac{N_1}{N_2}$ i.e. $\frac{500}{V_2} = \frac{400}{1000}$ i.e. $V_2 = \mathbf{1250 \ V}$

iii) $(I_2)_{F.L} = \frac{VA}{V_2} = \frac{4 \times 10^3}{1250} = \mathbf{3.2 \ A}$

Q.24 A 10 kVA, 3300/220 V 1-phase 50 Hz transformer has e.m.f. per turn equal to 10. Calculate : i) Turns on primary side ii) Turns on secondary side iii) Maximum flux in the core iv) Primary and secondary full load current

☞ [SPPU : May-17, Marks 6]

Ans. : 10 kVA, $E_1 = 3300$ V, $E_2 = 220$ V, e.m.f./turn = 10

i) $E_1 = [\text{e.m.f./turn}] \times N_1$ i.e. $N_1 = \frac{3300}{10} = \mathbf{330}$

ii) $E_2 = [\text{e.m.f./turn}] \times N_2$ i.e. $N_2 = \frac{220}{10} = \mathbf{22}$

Note : E.M.F. per turn remains same on both the sides of a transformer.

iii) $E_1 = 4.44 \phi_m f N_1$ ... f = 50 Hz

$\therefore \quad \phi_m = \frac{3300}{4.44 \times 50 \times 330} = \mathbf{45.045\ mWb}$

iv) $I_1(\text{FL}) = \frac{\text{VA}}{E_1} = \frac{10 \times 10^3}{3300} = \mathbf{3.0303\ A}$

$I_2(\text{FL}) = \frac{\text{VA}}{E_2} = \frac{10 \times 10^3}{220} = \mathbf{45.4545\ A}$

Q.25 A single phase 50 Hz transformer has 300 primary turns and 750 secondary turns. The net cross-sectional area of the core is 64 cm^2. If the primary induced emf is 400 V, find : i) Maximum flux in the core ii) Maximum flux density in the core iii) emf induced in the secondary.

☞ [SPPU : Dec.-17, Marks 6]

Ans. : $N_1 = 300$, $N_2 = 750$, $a = 64\ \text{cm}^2$, $E_1 = 400$ V, f = 50 Hz

i) $E_1 = 4.44\, f \phi_m N_1$ i.e. $\phi_m = \frac{400}{4.44 \times 50 \times 300}$

$\therefore \quad \phi_m = \mathbf{6\ mWb}$

ii) $B_m = \frac{\phi_m}{a} = \frac{6 \times 10^{-3}}{64 \times 10^{-4}} = \mathbf{0.9384\ Wb/m^2}$

iii) $\frac{E_1}{E_2} = \frac{N_1}{N_2}$ i.e. $\frac{400}{E_2} = \frac{300}{750}$ i.e. $E_2 = \mathbf{1000\ V}$

Q.26 A 50 kVA single phase transformer has a turns ratio of 300/20. The primary winding is connected to a 2200 V, 50 Hz supply. Calculate.

i) The secondary voltage at no load

ii) The approximate value of primary current on full load.

iii) The approximate value of secondary current on full load.

☞ [SPPU : May-18, Marks 6]

Ans. : Refer Q.24 for the procedure and verify the answers as :

i) $E_2 = \mathbf{146.667\ V}$ ii) $I_1(\text{FL}) = \mathbf{22.727\ A}$ iii) $I_2(\text{FL}) = \mathbf{340.91\ A}$

4.12 : Equivalent Resistance of Transformer

Q.27 How to calculate equivalent resistance referred to primary and secondary in a transformer ?

Ans. : Let R_1 = Primary winding resistance in ohms

R_2 = Secondary winding resistance in ohms

- The resistance of the two windings can be transferred to any one side either primary or secondary without affecting the performance of the transformer.
- The total copper loss due to both the resistances can be obtained as,

$$\text{Total copper loss} = I_1^2 R_1 + I_2^2 R_2 = I_1^2 \left[R_1 + \frac{I_2^2}{I_1^2} R_2 \right]$$

$$= I_1^2 \left[R_1 + \frac{1}{K^2} R_2 \right] \left(\frac{I_2}{I_1} = \frac{1}{K} \right) \qquad \ldots (1)$$

- Now the expression (1) indicates that the total copper loss can be expressed as $I_1^2 R_1 + I_1^2 \cdot \frac{R_2}{K^2}$. This means $\frac{R_2}{K^2}$ is the resistance value of R_2 shifted to primary side which causes same copper loss with I_1 as R_2 causes with I_2.
- This value of resistance R_2/K^2 which is the value of R_2 referred to primary is called **equivalent resistance of secondary referred to primary**. It is denoted as R_2'.

$$\boxed{R_2' = \frac{R_2}{K^2}}$$

- Hence the **total resistance referred to primary** is the additio R₁ and R_2' called equivalent resistance of transformer referred primary and denoted as R_{1e}.

$$\therefore \quad \boxed{R_{1e} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}}$$

- Similarly the **equivalent resistance of primary referred secondary is,**

$$\therefore \quad R_1' = K^2 R_1$$

Hence the total resistance referred to secondary is the addition R_2 and R_1' called **equivalent resistance of transformer referred secondary** and denoted as R_{2e}.

$$\therefore \quad \boxed{R_{2e} = R_2 + R_1' = R_2 + K^2 R_1}$$

High voltage side → Low current side → High resistance side

Low voltage side → High current side → Low resistance side

Important Points to Remember

- The transformer primary and secondary windings have the leakage reactances denoted as X_1 and X_2 respectively.
- Similar to resistances the leakage reactances also can b transferred from primary to secondary or vice-versa.
- The total leakage reactance referred to primary is X_{1e} given by

$$X_{1e} = X_1 + X_2' \quad \text{where} \quad X_2' = \frac{X_2}{K^2}$$

- While the total leakage reactance referred to secondary is X_2 given by,

$$X_{2e} = X_2 + X_1' \quad \text{where} \quad X_1' = K^2 X_1 \qquad \ldots K = \frac{N_2}{N_1}$$

- The total impedance of primary winding is $Z_1 = R_1 + j X_1 \ \Omega$
- The total impedance of the secondary winding is

$$Z_2 = R_2 + j X_2 \ \Omega$$

- Let Z_{1e} = Total equivalent impedance referred to primary then,

$$Z_{1e} = R_{1e} + j X_{1e} \qquad \ldots(1)$$

$$\therefore \quad Z_{1e} = Z_1 + Z_2' = Z_1 + \frac{Z_2}{K^2} \qquad \ldots(2)$$

- Similarly Z_{2e} = Total equivalent impedance referred to secondary then,

$$Z_{2e} = R_{2e} + j X_{2e} \qquad \ldots(3)$$

$$\therefore \quad Z_{2e} = Z_2 + Z_1' = Z_2 + K^2 Z_1 \qquad \ldots(4)$$

- The magnitudes of Z_{1e} and Z_{2e} are,

$$Z_{1e} = \sqrt{R_{1e}^2 + X_{1e}^2} \quad \text{and} \quad Z_{2e} = \sqrt{R_{2e}^2 + X_{2e}^2} \qquad \ldots(5)$$

4.13 : Voltage Regulation of Transformer

Q.28 Why secondary terminal voltage reduces on load ?

☞ [SPPU : May-05, Dec.-06, Marks 3]

Ans. : As the transformer is loaded, it draws more current. Thus there is increse in its primary as well as secondary current.

- There is voltage drop taking place across the winding resistances and leakage reactances.
- As the current increases, the voltage drops across the winding parameters also increases.
- Because of the voltage drop across the primary and secondary impedances it is observed that the secondary terminal voltage

drops from its no load value (E_2) to load value (V_2) as load and load current increases.

- Hence the secondary voltage reduces on load in transformers.

Thus $\boxed{V_2 = E_2 - \text{voltage drops across winding parameters}}$

Q.29 Define regulation of transformer. State its expression. How it depends on the load power factor ? Sketch the regulation characteristics. ☞ [SPPU : May-06, Marks 6]

Ans. : As load on the transformer increases, the secondary voltage decreases from its no load value.

- This decrease in the secondary terminal voltage expressed as a fraction of the secondary terminal voltage is called **regulation** of a transformer.
- The **regulation** is defined as the change in the magnitude of the secondary terminal voltage when rated load at specified power factor is reduced to no load, with primary voltage maintained constant expressed as the percentage of the rated terminal voltage.
- Let E_2 = Secondary terminal voltage on no load
  V_2 = Secondary terminal voltage on given load

then mathematically voltage regulation at given load can be expressed as,

$$\boxed{\%\ \text{Voltage regulation} = \frac{E_2 - V_2}{V_2} \times 100}$$

- The ratio $((E_2 - V_2)/V_2)$ is called **per unit regulation.**
- The secondary terminal voltage does not depend only on the magnitude of the load current but also on the nature of the power factor of the load.
- In case of lagging power factor $V_2 < E_2$ and we get positive voltage regulation, while for leading power factor $E_2 < V_2$ and we get negative voltage regulation.

- The Fig. Q.29.1 shows the regulation characteristics of transformer at different load power factors.

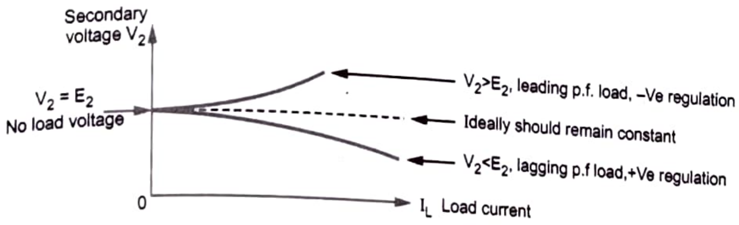


Fig. Q.29.1 Regulation characteristics at different power factors

Important Points to Remember

- The voltage regulation of transformer can be expressed as,

$$\% R = \frac{I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi}{V_2} \times 100$$

where I_2 = Secondary current on load,
V_2 = Secondary voltage on load
R_{2e} = Equivalent resistance referred to secondary
X_{2e} = Equivalent reactance referred to secondary
$\cos\phi$ = Load power factor

∴ '+'sign for lagging power factors while'–'sign for leading power factor loads.

- The regulation can be expressed interms of I_1, V_1, R_{1e} and X_{1e} as,

$$\% R = \frac{I_1 R_{1e} \cos\phi \pm I_1 X_{1e} \sin\phi}{V_1} \times 100$$

4.14 : Losses in Transformer

Q.30 Explain the various losses in a transformer. In which part these losses occur ? How to minimize them ? On which factors they depend ?

☞ [SPPU : May-04,06,07,08,10,11,12,14, Dec.-06,07,08,10, Marks 6]

Ans. : In a transformer, there exists two types of losses.

i) Core losses or iron losses and ii) Copper losses

1. Core or Iron losses

- Due to alternating flux set up in the magnetic core of the transformer, it undergoes a cycle of magnetisation and demagnetisation.
- Due to hysteresis effect there is loss of energy in this process which is called hysteresis loss.

It is given by,

$$\boxed{\text{Hysteresis loss} = K_h\, B_m^{1.67}\, f\, v \quad \text{watts}}$$

K_h = Hysteresis constant depends on material and

B_m = Maximum flux density

f = Frequency and v = Volume of the core.

- The induced e.m.f. in the core tries to set up eddy currents in the core and hence responsible for the eddy current losses. The eddy current loss is given by,

$$\boxed{\text{Eddy current loss} = K_e\, B_m^2\, f^2 t^2 \quad \text{watts/unit volume}}$$

where K_e = Eddy current constant

and t = Thickness of the core.

- The flux in the core is constant as supply voltage V_1 at rated frequency f is always constant. Hence, the flux density B_m in the core and hence both hysteresis and eddy current losses are constant losses at all the loads.
- The iron losses are minimized by using high grade core material like silicon steel having very low hysteresis loop and by manufacturing the core in the form of laminations.

2. Copper losses

- The copper losses are due to the power wasted in the form of I^2R loss due to the resistances of the primary and secondary windings.
- The copper loss depends on the magnitude of the currents flowing through the windings and the winding resistances.
- Total Cu loss $= I_1^2 R_1 + I_2^2 R_2 = I_1^2 (R_1 + R_2') = I_2^2 (R_2 + R_1') = I_1^2 R_{1e}$

  $= I_2^2 R_{2e}$.
- As the current in the winding depends on the load, the copper losses also vary with the load. Thus copper losses are called **variable losses.**
- Thus for a transformer,

$$\boxed{\text{Total losses} = \text{Iron losses} + \text{Copper losses}}$$

- The copper losses are kept minimum by designing the windings with low resistance values.

4.15 : Efficiency of Transformer

Q.31 Define efficiency of transformer. Obtain the expression for it.

☞ [SPPU : May-06, Marks 4]

Ans. : Due to the losses in a transformer, the output power of a transformer is less than the input power supplied.

$\therefore$ Power output = Power input – Total losses

$\therefore$ Power input = Power output + Total losses

= Power output + P_i + P_{Cu}

where P_i = Iron losses and P_{Cu} = Copper losses

- The efficiency of any device is defined as the ratio of the power output to power input.
- So for a transformer the efficiency can be expressed as,

$$\eta = \frac{\text{Power output}}{\text{Power input}} = \frac{\text{Power output}}{\text{Power output} + P_i + P_{Cu}}$$

- Power output = $V_2 I_2 \cos\phi$ where $\cos\phi$ = Load power factor
- The transformer supplies full load of current I_2 and with terminal voltage V_2.

$$P_{Cu} = \text{Copper losses on full load} = I_2^2 R_{2e} \text{ or } = I_1^2 R_{1e}$$

$$\therefore \quad \eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_{Cu}} \quad \text{but}$$

$$V_2 I_2 = \text{VA rating of a transformer}$$

$$\therefore \quad \boxed{\% \eta = \frac{(\text{VA rating}) \times \cos\phi}{(\text{VA rating}) \times \cos\phi + P_i + P_{Cu}} \times 100}$$

- This is full load percentage efficiency with I_2 = Full load secondary current.

Important Points to Remember

- If the transformer is subjected to fractional load then using the appropriate values of various quantities, the efficiency can be obtained.

Let n = Fraction by which load is different than full load

$$= \frac{\text{Actual load}}{\text{Full load}}$$

- For example, if transformer is subjected to half load then, $n = \frac{\text{Half load}}{\text{Full load}} = \frac{(1/2)}{1} = 0.5$
- When load changes, the load current changes by same proportion.

$$\therefore \quad \text{New } I_2 = n\,(I_2)\text{F.L.}$$

- Similarly the output $V_2 I_2 \cos\phi_2$ also reduces by the same fraction. Thus fraction of VA rating is available at the output.
- Similarly as copper losses are proportional to square of current then,

$$\therefore \quad \text{New } P_{Cu} = n^2 (P_{Cu})\text{ F.L.}$$

- **The copper losses get reduced by n^2 while iron losses remain same.**
- In general for fractional load the efficiency is given by,

$$\% \eta = \frac{n\,(\text{VA rating}) \cos\phi}{n\,(\text{VA rating}) \cos\phi + P_i + n^2 (P_{Cu})\text{F.L.}} \times 100$$

where, **n = Fraction by which load is less than full load.**

For all types of load power factors lagging, leading and unity the efficiency expression does not change and remains same.

4.16 : Condition for Maximum Efficiency

Q.32 Derive the condition for the maximum efficiency for a transformer.

Ans. : The load current at which the efficiency attains maximum value is denoted as I_{2m} and maximum efficiency is denoted as η_{max}.

- The efficiency is a function of load i.e. load current I_2 assuming $\cos\phi_2$ constant. The secondary terminal voltage V_2 is also assumed constant.
- So for maximum efficiency,

$$\frac{d\eta}{dI_2} = 0 \quad \text{while} \quad \eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e}}$$

$$\therefore \quad \frac{d\eta}{dI_2} = \frac{d}{dI_2}\left[\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e}}\right] = 0$$

$$\therefore \quad (V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e})(V_2 \cos\phi_2) - (V_2 I_2 \cos\phi_2)(V_2 \cos\phi_2 + 2 I_2 R_{2e}) = 0$$

- Cancelling $(V_2 \cos\phi_2)$ from both the terms we get,

$$V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e} - V_2 I_2 \cos\phi_2 - 2 I_2^2 R_{2e} = 0$$

i.e. $P_i - I_2^2 R_{2e} = 0$

$\therefore$ $$\boxed{P_i = I_2^2 R_{2e} = P_{Cu}}$$

So condition to achieve maximum efficiency is that,

$$\boxed{\text{Copper losses = Iron losses} \quad \text{i.e.} \quad P_i = P_{Cu}}$$

Important Points to Remember

- For η_{max}, copper losses = Iron losses

  $\therefore$ $P_i = P_{cu}$ ... for η_{max}

- Load current I_{2m} at maximum efficiency is given by,

  $$I_{2m} = \sqrt{\frac{P_i}{R_{2e}}} \quad \text{... This is the load current at } \eta_{max}$$

- I_{2m} can be expressed in terms of full load current as,

  $$\frac{I_{2m}}{(I_2)\text{F.L.}} = \frac{1}{(I_2)\text{F.L.}}\sqrt{\frac{P_i}{R_{2e}}}$$

  i.e. $$\frac{I_{2m}}{(I_2)\text{F.L.}} = \sqrt{\frac{P_i}{[(I_2)\text{F.L.}]^2 R_{2e}}} = \sqrt{\frac{P_i}{(P_{Cu})\text{F.L.}}}$$

  $\therefore$ $$I_{2m} = (I_2)\text{F.L.}\sqrt{\frac{P_i}{(P_{Cu})\text{F.L.}}}$$

- kVA supplied at maximum efficiency is given by,

  $$\text{kVA at } \eta_{max} = I_{2m} V_2 = V_2 (I_2)\text{F.L.} \times \sqrt{\frac{P_i}{(P_{Cu})\text{F.L.}}}$$

  $\therefore$ $$\text{kVA at } \eta_{max} = (\text{kVA rating}) \times \sqrt{\frac{P_i}{(P_{Cu})\text{F.L.}}}$$

- Substituting condition for η_{max} in the expression of efficiency, we can write expression for η_{max} as,

  $$\% \eta_{max} = \frac{V_2 I_{2m} \cos\phi}{V_2 I_{2m} \cos\phi + 2P_i} \times 100 \quad \text{as } P_{Cu} = P_i$$

Q.33 A 3300/110 V, 50 Hz, 50 kVA transformer has full load copper load of 1600 watts and iron loss of 1800 watts. Estimate the transformer efficiency at :

i) Full load and 0.7 lagging pf. ii) Half load and 0.85 lagging pf.

☞ [SPPU : Dec.-16, Marks 6]

Ans. : P_{cu} (FL) = 1600 W, P_i = 1800 W, 50 kVA

i) Full load, n = 1, $\cos\phi = 0.7$

$$\% \eta = \frac{n \text{ VA} \cos\phi}{n\text{VA} \cos\phi + P_i + [n^2 P_{cu} \text{ (FL)}]} \times 100$$

$$= \frac{50 \times 10^3 \times 0.7}{50 \times 10^3 \times 0.7 + 1800 + 1600} \times 100 = \mathbf{91.146\ \%}$$

ii) Half load, n = 0.5, $\cos\phi = 0.85$

$$\% \eta = \frac{0.5 \times 50 \times 10^3 \times 0.85}{0.5 \times 50 \times 10^3 \times 0.85 + 1800 + [0.5^2 \times 1600]} \times 100 = \mathbf{90.618\ \%}$$

Q.34 A 600 kVA transformer has iron losses of 4 kW and half load copper losses are 2 kW. Calculate the efficiency of transformer at i) Half load 0.8 p.f. lagging and ii) Full load 0.8 p.f. lagging.

☞ [SPPU : Dec.-14, Marks 6]

Ans. : 600 kVA , P_i = 4 kW , P_{cu}(HL) = 2 kW

$$\therefore \quad P_{cu} \propto (\text{VA})^2 \quad \text{i.e.} \quad \frac{P_{cu}(\text{FL})}{P_{cu}(\text{HL})} = \left(\frac{\text{VA}}{\frac{1}{2}\text{VA}}\right)^2 = 4$$

$$\therefore \quad P_{cu}(\text{FL}) = 4 \times P_{cu}(\text{HL}) = 4 \times 2 = 8 \text{ kW}$$

i) Half load, $\cos\phi = 0.8$

$$\therefore \quad \% \eta = \frac{n \text{ VA} \cos\phi}{n \text{ VA} \cos\phi + P_i + n^2 P_{cu}(\text{FL})} \times 100 \quad \text{... n = 0.5 for half load}$$

$$= \frac{0.5 \times 600 \times 10^3 \times 0.8}{0.5 \times 600 \times 10^3 \times 0.8 + 4 \times 10^3 + 2 \times 10^3} \times 100 = \mathbf{97.56\ \%}$$

ii) Full load, $\cos\phi = 0.8$

$$\therefore \quad \%\eta = \frac{\text{VA}\cos\phi}{\text{VA}\cos\phi + P_i + P_{cu}\,(\text{FL})} \times 100$$

$$= \frac{600\times10^3\times0.8}{600\times10^3\times0.8+4\times10^3+8\times10^3}\times100 = \mathbf{97.56\ \%}$$

Q.35 A transformer is rated at 100 kVA. At full load, its copper loss is 1200 W and its iron loss is 960 W.
Calculate : i) Efficiency at full load, 0.8 power factor.
ii) Load kVA at which maximum efficiency will occur.
iii) Maximum efficiency at 0.85 power factor.

☞ **[SPPU : May-14, Marks 6]**

Ans : $P_i = 960\ \text{W}, (P_{cu})\text{F.L.} = 1200\ \text{W}, 100\ \text{kVA}$

i) $$\%\eta_{FL} = \frac{\text{VA}\cos\phi}{\text{VA}\cos\phi + P_i + (P_{Cu})\text{F.L.}}\times100$$

$$= \frac{100\times10^3\times0.8\times100}{100\times10^3\times0.8+960+1200} = \mathbf{97.37\ \%}$$

ii) $$\text{kVA at } \eta_{max} = \text{kVA}\times\sqrt{\frac{P_i}{(P_{Cu})\text{F.L}}} = 100\times\sqrt{\frac{960}{1200}} = \mathbf{89.4427\ kVA}$$

iii) $\cos\phi = 0.85,\ P_i = P_{Cu} = 960\ \text{W}$

$$\therefore \quad \%\ \eta_{max} = \frac{\text{kVA at } \eta_{max}\times\cos\phi}{\text{kVA at } \eta_{max}\times\cos\phi + 2P_i}\times100$$

$$= \frac{89.4427\times10^3\times0.85}{59.4427\times10^3\times0.85+2\times960}\times100 = \mathbf{97.536\ \%}$$

Q.36 A 40 kVA, 2200/220 V, 50 Hz, 1-ph transformer has an iron loss of 250 W. The resistances of low and high voltage windings are 0.005 Ω and 0.5 Ω respectively. Calculate efficiency at full load and load p.f. = 0.8 lagging. ☞ **[SPPU : Dec.15, Marks 7]**

Ans. : 40 kVA, $V_1 = 2200$ V, $V_2 = 220$ V, $P_i = 250$ W, $R_1 = 0.5\ \Omega$,

$$R_2 = 0.005\ \Omega,\ \cos\phi = 0.8,\ K = \frac{V_2}{V_1} = 0.1$$

$$\therefore \quad R_{1e} = R_1 + \frac{R_2}{K^2} = 0.5 + \frac{0.005}{(0.1)^2} = 1\ \Omega$$

$$I_1(\text{FL}) = \frac{\text{VA}}{V_1} = \frac{40\times10^3}{2200} = 18.1818\ \text{A}$$

$$\therefore \quad P_{cu}\,(\text{FL}) = [I_1(\text{FL})]^2\times R_{1e} = 330.578\ \text{W}$$

$$\therefore \quad \%\eta_{FL} = \frac{\text{VA}\cos\phi}{\text{VA}\cos\phi + P_i + P_{cu}\,(\text{FL})}\times100$$

$$= \frac{40\times10^3\times0.8}{40\times10^3\times0.8+250+330.578}\times100 = \mathbf{98.218\ \%}$$

Q.37 A 80 kVA, 1000/250 V, 1-ph 50 Hz transformer has iron loss of 800 W and full load copper loss 1200 W. Find [i] efficiency at full load and power factor = 08 lag. [ii] efficiency at half load and power factor = 1.

☞ **[SPPU : May-19, Marks 6]**

Ans. : Given : 80 kVA, $P_i = 800$ W, $P_{cu}(\text{FL}) = 1200$ W

To find : η_{FL}, η_{HL}

i) Full load, $n = 1$, $\cos\phi = 0.8$

$$\%\ \eta = \frac{n(\text{VA})\cos\phi}{n(\text{VA})\cos\phi + P_i + [n^2 P_{cu}(\text{FL})]}\times100$$

$$\therefore \quad \%\ \eta_{FL} = \frac{1\times80\times10^3\times0.8}{1\times80\times10^3\times0.8+800+[1^2\times1200]}\times100 = \mathbf{96.97\ \%}$$

ii) Half load, $n = 0.5$, $\cos\phi = 1$

$$\therefore \quad \%\ \eta_{HL} = \frac{0.5\times80\times10^3\times1}{0.5\times80\times10^3\times1+800+[0.5^2\times1200]}\times100 = \mathbf{97.32\ \%}$$

4.17 : Direct Loading Method of Finding Efficiency and Regulation

Q.38 With the help of neat circuit diagram, describe the method of testing a single phase transformer by direct laoding. Explain how the efficiency and regulation are calculated from the test results.

☞ **[SPPU : May-05,07,08,16, Dec.-03,09, Marks 6]**

Ans. : In the direct loading method, transformer secondary is connected to the desired load directly for which efficiency and regulation is required.

- Experimental set up for the test is shown in the Fig. Q.38.1.

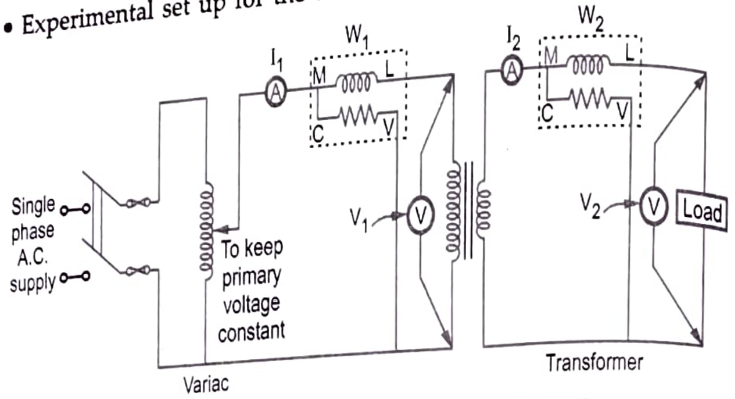


Fig. Q.38.1 Experimental circuit of direct loading

- On primary and secondary ammeter, voltmeter and wattmeter are connected to measure currents, voltages and wattage on both sides of transformer.
- The procedure to perform the test is,

1. Make sure that load is off.
2. Switch on the supply and adjust variac to get rated primary voltage to be observed on voltmeter as V_1.
3. Observe the reading on no load first and note down V_1, I_1, W_1, V_2, I_2 and W_2. It can be observed that on no load $I_2 = 0$ and $W_2 = 0$. Hence $V_2 = E_2$.
4. Switch on the load step by step and note down the various readings.

> Keep primary voltage always constant with the help of variac, at its rated value.

- The following observation table is prepared -

Sr. No.	Primary Side			Secondary Side			
	V_1	I_1	W_1	V_2	I_2	W_2	
1	Rated	...	...	E_2 V	0 A	0 W	⇐ No load reading
2	Rated	...	...	...	...	...	
3	Rated	...	...	...	...	...	

The efficiency and regulation can be obtained as,

W_1 = Input power to primary and

W_2 = Output power delivered to load

$$\therefore \quad \boxed{\% \eta = \frac{W_2}{W_1} \times 100}$$

- While the regulation can be obtained as,

$$\therefore \quad \boxed{\% R = \frac{E_2 - V_2}{E_2} \times 100 \qquad \text{where } E_2 \text{ is constant}}$$

- As $E_2 = V_2$ on no load condition the regulation is zero on no load. For other loads regulation can be obtained by using the above expression. The V_2 represents secondary terminal voltage on various loads.

Q.39 A direct loading test is to be conducted on 1-phase 230/110 V, 2 kVA transformer to determine efficiency and voltage regulation. Draw the neat connection diagram and write down the ranges of the meters used with reasons. ☞ [SPPU : May-17, Marks 6]

Ans. : Connection diagram : Refer Fig. Q.38.1

Meter ranges :

$$I_1(FL) = \frac{VA}{V_1} = \frac{2 \times 10^3}{230} = 8.695 \text{ A}$$

$$I_2(FL) = \frac{VA}{V_2} = \frac{2 \times 10^3}{110} = 18.18 \text{ A}$$

For primary : Voltmeter : 0 - 250 V, Ammeter : 0 - 10 A and Wattmeter : 250 V, 10 A

For secondary : Voltmeter : 0 - 150 V, Ammeter : 0 - 20 A and Wattmeter : 150 V, 20 A

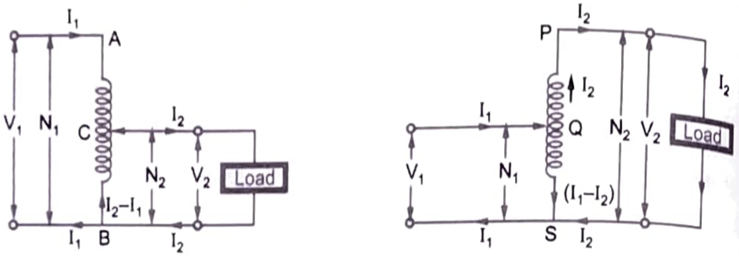
4.18 : Autotransformer

Q.40 Write a note on autotransformer. ☞ [SPPU : Dec.-03,05,07,09,10,16, May-06,07,08,10,11, Marks 4]

OR Explain the working principle of autotransformer.

Ans. : An autotransformer is a special type of transformer such that a part of the winding is common to both primary as well as secondary. It has only winding wound on a laminated magnetic core.

- With the help of autotransformer the voltage can be stepped down or can be stepped up also, to any desired value.
- The Fig. Q.40.1 (a) shows the step down autotransformer. AB acts as a primary winding while part of the primary winding BC acts as a secondary winding.
- The position of C called as % tapping point, can be selected as per the requirement of the secondary voltage.
- Fig. Q.40.1 (b) shows the step up autotransformer where QS acts as a primary winding while PS acts as a secondary winding.



(a) Step down **Fig. Q.40.1 Autotransformer** **(b) Step up**

- The operating principle of the autotransformer is same as that of two winding transformer.
- The current in the portion CB i.e. secondary, in case of step down auto transformer is the vector difference of I_2 and I_1 while the current in the portion QS i.e. primary, in case of step up autotransformer is the vector difference of I_2 and I_1.
- Neglecting the losses, the leakage reactance and the magnetising current we can write the transformation ratio of the autotransformer as

$$K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

- Due to the use of single winding, compared to normal two winding transformer, for the same capacity and voltage ratio, there is substantial **saving in copper**, in autotransformer.

Q.41 State the advantages, disadvantages and applications of autotransformer. ☞ **[SPPU : May-10, Dec.-03, 09, 16, Marks 6]**

Ans. : The **advantages** of autotransformer are,

1) Copper required is very less.
2) The efficiency is higher compared to two winding transformer.
3) The size and hence cost is less compared to two winding transformer.
4) The resistance and leakage reactance is less compared to two winding transformer.
5) The copper losses I^2R, are less.
6) Due to less resistance and leakage reactance, the voltage regulation is superior than the two winding transformer.

The **disadvantages** of autotransformer are,

1) Low impedance hence high short circuit currents for short circuits on secondary side.
2) If a section of winding common to primary and secondary is opened, full primary voltage appears across the secondary resulting in higher voltage on secondary and danger of accidents.
3) No electrical separation between primary and secondary which is risky in case of high voltage levels.

The **applications** of autotransformer are,

1) For interconnecting systems which are operating roughly at same voltage.
2) For starting rotating machines like induction motors, synchronous motors.
3) To give a small boost to a distribution cable to correct for the voltage drop.
4) As a furnace transformer for getting required supply voltage.
5) As a variac, to vary the voltage to the load, smoothly from zero to the rated value. Such variacs are commonly used for dimming the lights in cinema halls. Hence the variacs are also called **dimmerstats.**

END...

UNIT - V

5

D.C. Circuits

Important Points to Remember

- Any arrangement of the various electrical energy sources along with the different circuit elements is called an **electrical network.**
- A part of the network which connects the various points of the network with one another is called **a branch.**
- A point where three or more branches meet is called a **junction point.**
- A point at which two or more branches meet is called **node.** The junction points are also the nodes of the network.
- Mesh (or Loop) is a set of branches forming a closed path in a network in such a way that if one branch is removed then remaining branches do not form a closed path.

5.1 : Classification of Electrical Networks

Q.1 Classify the electrical networks.

☞[SPPU : May-04,12,08, Dec.-03,08,09,11, Marks 6]

Ans. : The electrical networks are classified as,

i) Linear Network :

- A circuit or network whose parameters i.e. elements like resistances, inductances and capacitances are always constant irrespective of the change in time, voltage, temperature etc. is known as **linear network**.

ii) Non linear Network :

- A circuit whose parameters change their values with change in time, temperature, voltage etc. is known as **non linear network** .
- The best example is a circuit consisting of a diode where diode current does not vary linearly with the voltage applied to it.

iii) Bilateral Network :

- A circuit whose characteristics, behaviour is same irrespective of the direction of current through various elements of it, is called **bilateral network.**
- Network consisting only resistances is good example of bilateral network.

iv) Unilateral Network :

- A circuit whose operation, behaviour is dependent on the direction of the current through various elements is called **unilateral network**.
- Circuit consisting diodes, which allows flow of current only in one direction is good example of unilateral circuit.

v) Active Network :

- A circuit which contains at least one source of energy is called **active.** An energy source may be a voltage or current source.

vi) Passive Network :

- A circuit which contains no energy source is called **passive** circuit.

vii) Lumped Network :

- A network in which all the network elements are physically separable is known as **lumped network**.
- Most of the electric networks are lumped in nature, which consists elements like R, L, C, voltage source etc.

viii) Distributed Network :

- A network in which the circuit elements like resistance, inductance etc. cannot be physically separable for analysis purposes, is called **distributed network**.

- The best example of such a network is a transmission line where resistance, inductance and capacitance of a transmission line are distributed all along its length and cannot be shown as a separate elements, any where in the circuit.

Q.2 Explain lumped and distributed networks.

☞ [SPPU : Dec.-11, Marks 2]

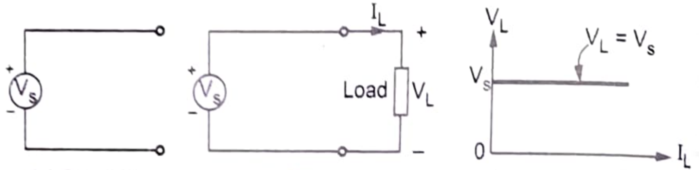
Ans. : Refer the part of lumped and distributed networks from the answer of Q.1 above.

5.2 : Energy Sources

Q.3 Explain ideal and practical voltage sources.

Ans. : Ideal voltage source is defined as the energy source which gives constant voltage across its terminals irrespective of the current drawn through its terminals.

- The symbol for ideal voltage source is shown in the Fig. Q.3.1 (a). This is connected to the load as shown in Fig. Q.3.1 (b).
- At any time the value of voltage at load terminals remains same. This is indicated by V- I characteristics shown in the Fig. Q.3.1 (c).

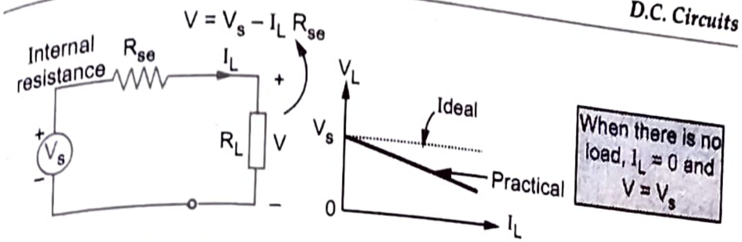


(a) Symbol (b) Circuit (c) Characteristics

Fig. Q.3.1 Ideal voltage source

Practical voltage source :

- But practically, every voltage source has small internal resistance shown in series with voltage source and is represented by R_{se} as shown in the Fig. Q.3.2. Ideally $R_{se} = 0\ \Omega$.
- Because of the R_{se}, voltage across terminals decreases slightly with increase in current.



(a) Circuit (b) Characteristics

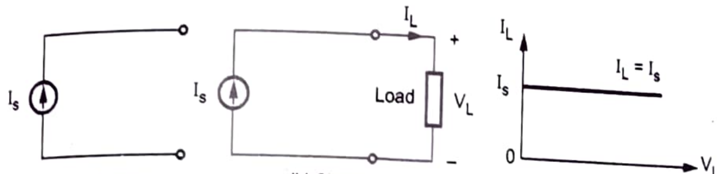
Fig. Q.3.2 Practical voltage source

Q.4 Explain ideal and practical current sources.

☞ [SPPU : May-06, Marks 4]

Ans. : Ideal current source is the source which gives constant current at its terminals irrespective of the voltage appearing across its terminals.

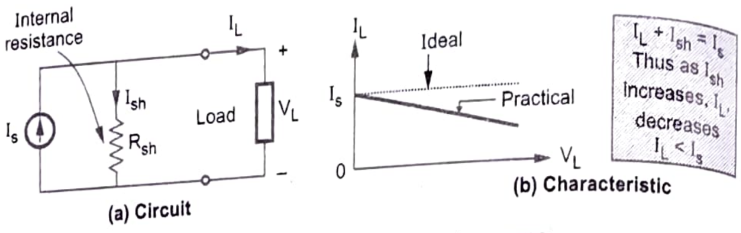
- The symbol for ideal current source is shown in the Fig. Q.4.1(a). This is connected to the load as shown in the Fig. Q.4.1(b).



(a) Symbol (b) Circuit (c) Characteristics

Fig. Q.4.1 Ideal current source

- At any time, the value of the current flowing through load I_L is same i.e. is irrespective of voltage appearing across its terminals. This is explained by V-I characteristics shown in the Fig. Q.4.1(c).
- But practically, every current source has high internal resistance, shown in parallel with current source and it is represented by R_{sh}. This is shown in the Fig. Q.4.2. Ideally $R_{sh} = \infty$.
- Because of R_{sh}, current through its terminals decreases slightly with increase in voltage at its terminals.



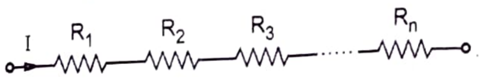
(a) Circuit (b) Characteristic

$I_L + I_{sh} = I_s$ Thus as I_{sh} increases, I_L decreases $I_L < I_s$

Fig. Q.4.2 Practical current source

5.3 : Series and Parallel Resistances

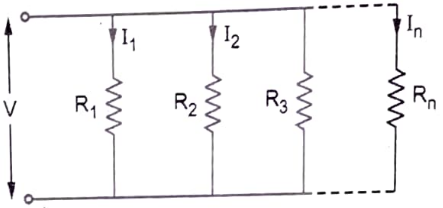
Important Points to Remember



'n' resistances in series current I is same.

Fig. 5.1

- For n resistances in series $R_{eq} = R_1 + R_2 + R_3 + \ldots\ldots + R_n$



'n' resistances in parallel. Voltage across them is same but currents are different.

Fig. 5.2

- In general if 'n' resistances are connected in parallel,

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots + \frac{1}{R_n}$$

- For two resistances in parallel,

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \quad \therefore \quad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

- **Current Division in Parallel Circuit of Two Resistors :**

If there are two resistances connected in parallel and the total current is I_T then the current in each resistance is given by,

$$\therefore \quad I_1 = \left[\frac{R_2}{R_1 + R_2}\right] I_T \quad \text{and} \quad I_2 = \left[\frac{R_1}{R_1 + R_2}\right] I_T$$

In general, the current in any branch is equal to the ratio of opposite branch resistance to the total resistance value, multiplied by the total current in the circuit.

Q.5 Find equivalent resistance between AB for the circuit shown in Fig. Q.5.1. ☞ **[SPPU : May-19, Marks 7]**

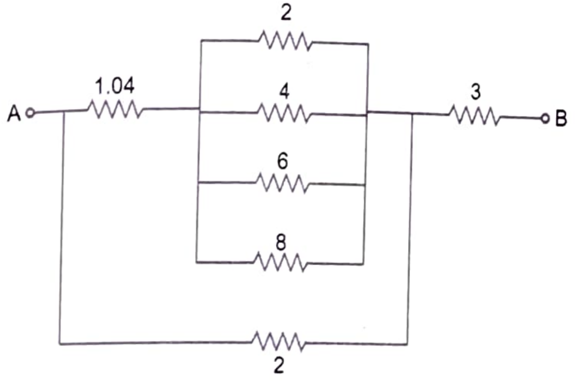
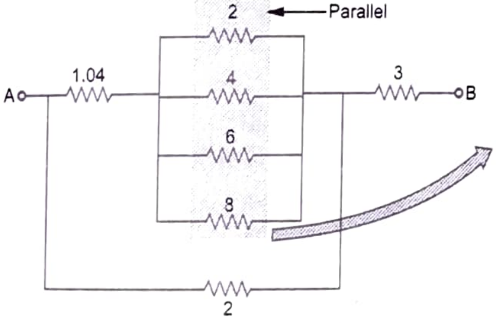


Fig. Q.5.1

Ans. : 2 Ω, 4 Ω, 6 Ω and 8 Ω are in parallel.



$$\frac{1}{R'} = \frac{1}{2} + \frac{1}{4} + \frac{1}{6} + \frac{1}{8}$$

$\therefore R' = 0.96\ \Omega$

Fig. Q.5.1 (a)

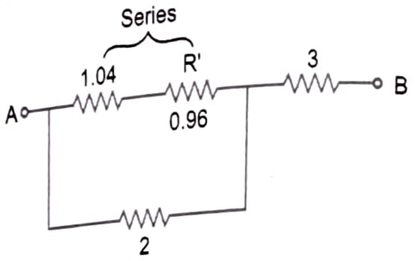


Fig. Q.5.1 (b)

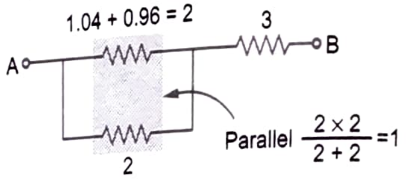


Fig. Q.5.1 (c)

$$\therefore \quad R_{AB} = 1 + 3$$
$$= 4\ \Omega$$

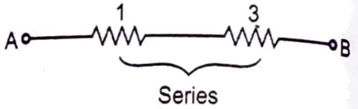


Fig. Q.5.1 (d)

5.4 : Kirchhoff's Laws

Q.6 State and explain Kirchhoff's laws.

☞ [SPPU : May-04, 05, 07, 11, 12, 13, 16, 17, Dec.-07, 10, 13, 14, 17, Marks 6]

Ans. : There are two Kirchhoff's laws.

1. Kirchhoff's Current Law (KCL)

- **The total current flowing towards a junction point is equal to the total current flowing away from that junction point.**
- Another way to state the law is,
- **The algebraic sum of all the current meeting at a junction point is always zero.**

$$\boxed{\sum I \text{ at junction point } = 0}$$

Sign convention : Currents flowing towards a junction point are assumed to be positive while currents flowing away from a junction point assumed to be negative.

- Consider a junction point in a complex network as shown in the Fig. Q.6.1. The currents I_1 and I_2 are positive as entering the junction while I_3 and I_4 are negative as leaving the junction.

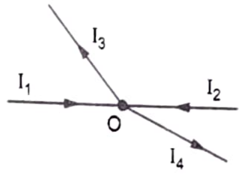


Fig. Q.6.1 Junction point

- Applying KCL, $\sum I$ at junction O = 0

$$I_1 + I_2 - I_3 - I_4 = 0 \qquad \text{i.e.} \qquad I_1 + I_2 = I_3 + I_4$$

2. Kirchhoff's Voltage Law (KVL)

"In any network, the algebraic sum of the voltage drops across the circuit elements of any closed path (or loop or mesh) is equal to the algebraic sum of the e.m.f. s in the path"

In other words, "the algebraic sum of all the branch voltages, around any closed path or closed loop is always zero."

$$\therefore \quad \boxed{\text{Around a closed path } \sum V = 0}$$

- The law states that if one starts at a certain point of a closed path and goes on tracing and noting all the potential changes (either drops or rises), in any one particular direction, till the starting point is reached again, he must be at the same potential with which he started tracing a closed path.
- Sum of all the potential rises must be equal to sum of all the potential drops while tracing any closed path of the circuit. The total change in potential along a closed path is always zero.

Sign convention for KVL :

- The current always flows from higher potential to lower potential. Hence the polarity of the voltage drop across the resistance along the current direction is to be marked as positive (+) to negative (–).
- While tracing a closed path for KVL, if we go from – ve marked terminal to + ve marked terminal, that voltage must be taken as positive. This is called **potential rise.**
- While tracing a closed path, if we go from +ve marked terminal to – ve marked terminal, that voltage must be taken as negative. This is called **potential drop**.
- The sum of all such potetial rises and potential drops must be zero for a closed loop under consideration, according to KVL.
- If there is current source in the network then complete the current distribution considering the current source. But while applying KVL, the loops **should not be considered involving current source. The loop equations must be written to those loops which do not include any current source.** This is because drop across current source is unknown.

Q.7 Apply Kirchhoff's law to calculate current drawn by 4 Ω resistance for the circuit.

☞ [SPPU : May-14, Marks 7]

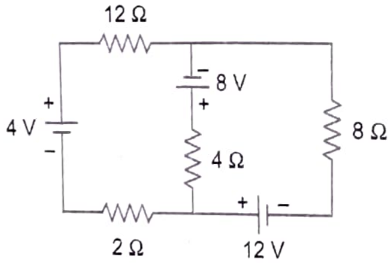


Fig. Q.7.1

Ans : The current distribution according to KCL is shown in the Fig. Q.7.1 (a).

Apply KVL to the loops I and II,

$$-12\,I_1 + 8 - 4\,I_2 - 2\,I_1 + 4 = 0 \quad \text{i.e.} \quad 14\,I_1 + 4\,I_2 = 12 \qquad \ldots (1)$$

$$-8\,(I_1 - I_2) + 12 + 4\,I_2 - 8 = 0$$

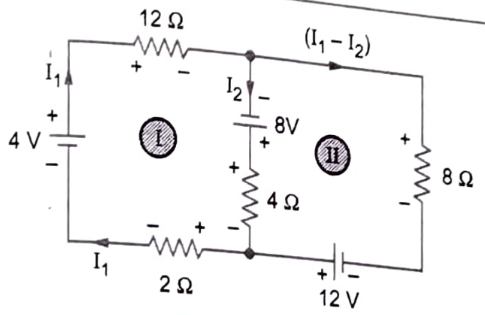


Fig. Q.7.1 (a)

$$\text{i.e.} \qquad +8\,I_1 - 12\,I_2 = 4 \qquad \ldots (2)$$

$$\text{Solving,} \qquad I_1 = 0.8\text{ A},\; I_2 = 0.2\text{ A}$$

$$\therefore \qquad I_{4\Omega} = I_2 = \mathbf{0.2\ A}$$

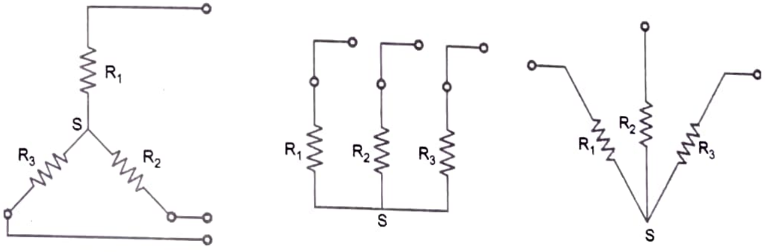
5.5 : Star and Delta Connection of Resistances

Q.8 Define star and delta connection of resistances.

☞ [SPPU : May-06, Dec.-09, Marks 3]

Ans. : If the three resistances are connected in such a manner that one end of each is connected together to form a junction point called **Star point**, the resistances are said to be connected in **Star**.

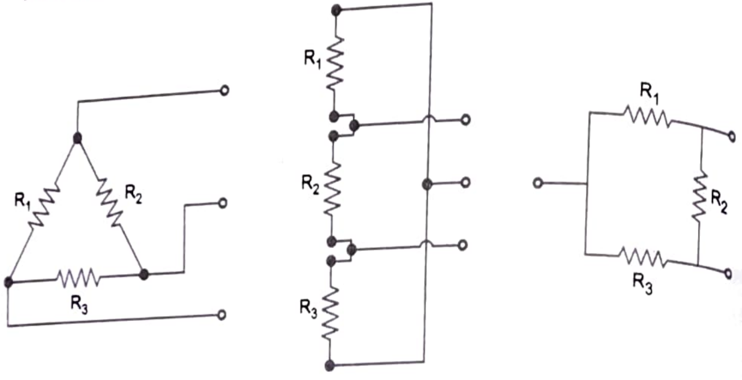
- The Fig. Q.8.1 (a), (b) and (c) show star connected resistances. The star point is indicated as S.



(a) (b) (c)

Fig. Q.8.1 Star connection of three resistances

- If the three resistances are connected in such a manner that one end of the first is connected to first end of second, the second end of second to first end of third and so on to complete a loop then the resistances are said to be connected in **Delta**.



(a) (b) (c)

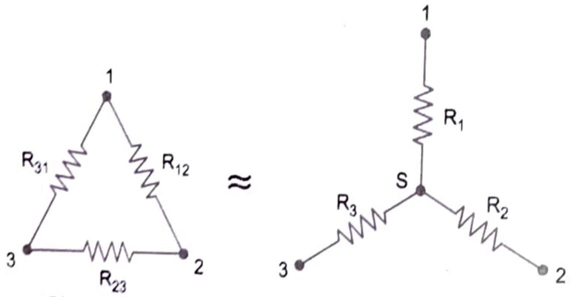
Fig. Q.8.2 Delta connection of three resistances

- The Fig. Q.8.2 (a), (b) and (c) show delta connection of three resistances.
- Delta connection always forms a loop, closed path.

Q.9 Derive equations to convert delta connected resistances to equivalent star connected resistances.

☞ **[SPPU : May-03,06,13,14,15,19, Dec.-04,05,11,14,15,18, Marks 6]**

Ans. : Consider the three resistances R_{12}, R_{23}, R_{31} connected in Delta as shown in the Fig. Q.9.1.



Given Delta

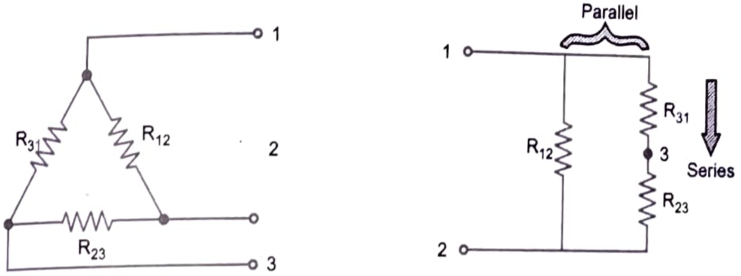
Equivalent Star

Fig. Q.9.1

- The terminals between which these are connected in Delta are named as 1, 2 and 3.
- It is always possible to replace these Delta connected resistances by three equivalent Star connected resistances R_1, R_2, R_3 between the same terminals 1, 2, and 3. Such a Star is shown inside the Delta in the Fig. Q.9.1 which is called **equivalent Star of Delta connected resistances.**

To call these two arrangements sas equivalent, the resistance between any two terminals must be same in both the types of connections.

- Let us analyse Delta connection first, shown in the Fig. Q.9.2 (a).
- Find equivalent resistance between 1 and 2. We can redraw the network as viewed from the terminals (1) and (2), without considering terminal 3. This is shown in the Fig. Q.9.2 (b).



(a) Given Delta

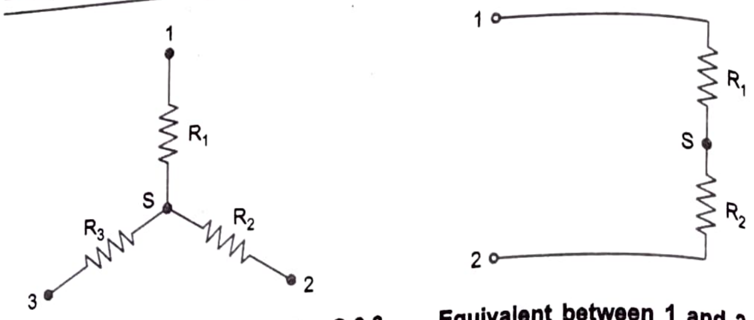
(b) Equivalent between 1 and 2

Fig. Q.9.2

- Between terminals (1) and (2) we get the combination as, R_{12} parallel with $(R_{31}+R_{23})$.

$\therefore$ Between (1) and (2) the resistance is
$$\frac{R_{12}(R_{31}+R_{23})}{R_{12}+(R_{31}+R_{23})} \qquad \ldots(1)$$

- Consider the same two terminals of equivalent Star connection shown in the Fig. Q.9.3.



Star Fig. Q.9.3 Equivalent between 1 and 2

- Terminal (3) is not getting connected anywhere and hence is not playing any role.

∴ Between (1) and (2) the resistance is = $R_1 + R_2$ ... (2)

- Equating equations (1) and (2),

$$\frac{R_{12}\left(R_{31}+R_{23}\right)}{R_{12}+\left(R_{23}+R_{31}\right)} = R_1 + R_2 \quad \ldots(3)$$

- Similarly if we find the equivalent resistance as viewed through terminals (2) and (3) in both the cases and equating, we get,

$$\frac{R_{23}\left(R_{31}+R_{12}\right)}{R_{12}+\left(R_{23}+R_{31}\right)} = R_2 + R_3 \quad \ldots(4)$$

- Simiarly if we find the equivalent resistance as viewed through terminals (3) and (1) in both the cases and equating, we get,

$$\frac{R_{31}\left(R_{12}+R_{23}\right)}{R_{12}+\left(R_{23}+R_{31}\right)} = R_3 + R_1 \quad \ldots(5)$$

- Subtracting (4) from (3),

$$\frac{R_{12}\left(R_{31}+R_{23}\right)-R_{23}\left(R_{31}+R_{12}\right)}{\left(R_{12}+R_{23}+R_{31}\right)} = R_1 + R_2 - R_2 - R_3$$

$$\therefore \quad R_1 - R_3 = \frac{R_{12}\;R_{31}-R_{23}\;R_{31}}{R_{12}+R_{23}+R_{31}} \quad \ldots(6)$$

- Adding (6) and (5),

$$\frac{R_{12}\;R_{31}-R_{23}\;R_{31}+R_{31}\left(R_{12}+R_{23}\right)}{R_{12}+R_{23}+R_{31}} = R_1 + R_3 + R_1 - R_3$$

$$\therefore \quad \frac{R_{12}\;R_{31}-R_{23}\;R_{31}+R_{31}\;R_{12}+R_{31}\;R_{23}}{R_{12}+R_{23}+R_{31}} = 2R_1$$

$$\text{i.e.} \quad 2R_1 = \frac{2\,R_{12}\;R_{31}}{R_{12}+R_{23}+R_{31}}$$

$$\boxed{R_1 = \frac{R_{12}\;R_{31}}{R_{12}+R_{23}+R_{31}}}$$

Similarly by using another combinations of subtraction and addition with equations (3), (4) and (5) we can get,

$$\therefore \quad \boxed{R_2 = \frac{R_{12}\;R_{23}}{R_{12}+R_{23}+R_{31}} \quad \text{and} \quad R_3 = \frac{R_{23}\;R_{31}}{R_{12}+R_{23}+R_{31}}}$$

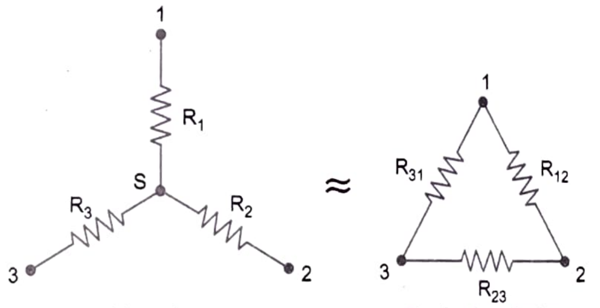
Important Points to Remember

- The equivalent star resistance between any terminal and star point is equal to the product of the two resistances in delta, which are connected to same terminal, divided by the sum of all three delta connected resistances.

Q.10 Derive an equations to convert star connected resistances to equivalent delta connected resistances.

☞ [SPPU : Dec.- 07, 09, 12, 16, May-09, 10, 12, 18, Marks 6]

Ans. : Consider the three resistances R_1, R_2 and R_3 connected in Star as shown in Fig. Q.10.1.



Given Star Equivalent Delta

Fig. Q.10.1

- By Star-Delta conversion, it is always possible to replace these Star connected resistances by three equivalent Delta connected resistances R_{12}, R_{23} and R_{31}, between the same terminals. This is called **equivalent Delta of the given star.**
- We are interested in finding out values of R_{12}, R_{23} and R_{31} interms of R_1, R_2 and R_3.
- From the result of Delta-Star transformation we know that,

$$R_1 = \frac{R_{12}\ R_{31}}{R_{12}+R_{23}+R_{31}} \quad \text{...(1)}$$

$$R_2 = \frac{R_{12}\ R_{23}}{R_{12}+R_{23}+R_{31}} \quad \text{...(2)}$$

$$R_3 = \frac{R_{23}\ R_{31}}{R_{12}+R_{23}+R_{31}} \quad \text{...(3)}$$

- Now multiply (1) and (2), (2) and (3), (3) and (4) to get following three equations.

$$R_1 R_2 = \frac{R_{12}^2\ R_{31}\ R_{23}}{(R_{12}+R_{23}+R_{31})^2} \quad \text{...(4)}$$

$$\therefore \quad R_2 R_3 = \frac{R_{23}{}^2\ R_{12}\ R_{31}}{(R_{12}+R_{23}+R_{31})^2} \quad \text{...(5)}$$

$$R_3 R_1 = \frac{R_{31}{}^2\ R_{12}\ R_{23}}{(R_{12}+R_{23}+R_{31})^2} \quad \text{...(6)}$$

- Now add (4), (5) and (6)

$$\therefore R_1 R_2 + R_2 R_3 + R_3 R_1 = \frac{R_{12}{}^2 R_{31} R_{23} + R_{23}{}^2 R_{12} R_{31} + R_{31}{}^2 R_{12}\ R_{23}}{(R_{12}+R_{23}+R_{31})^2}$$

$$\therefore \quad R_1 R_2 + R_2 R_3 + R_3 R_1 = \frac{R_{12} R_{31} R_{23}(R_{12}+R_{23}+R_{31})}{(R_{12}+R_{23}+R_{31})^2}$$

$$= \frac{R_{12} R_{31}\ R_{23}}{R_{12}+R_{23}+R_{31}}$$

$$\text{But} \quad \frac{R_{12} R_{31}}{R_{12}+R_{23}+R_{31}} = R_1 \quad \text{... From equation (1)}$$

$\therefore$ Substituting in above in R.H.S. we get,

$$\therefore \quad R_1 R_2 + R_2 R_3 + R_3 R_1 = R_1\ R_{23}$$

$$\therefore \quad \boxed{R_{23} = R_2 + R_3 + \frac{R_2\ R_3}{R_1}}$$

- Similarly substituting in R.H.S., remaining values from equations (2) and (3), we can write relations for remaining two resistances as,

$$\boxed{R_{12} = R_1 + R_2 + \frac{R_1\ R_2}{R_3} \quad \text{and} \quad R_{31} = R_3 + R_1 + \frac{R_1\ R_3}{R_2}}$$

Important Points to Remember

- The equivalent delta connected resistance to be connected between any two terminals is sum of the two resistances connected between the same two terminals and star point respectively in star, plus the product of the same two star resistances divided by the third star resistance.

Result for equal resistances in star and delta :

- If all resistances in a Delta connection have same magnitude say R, then its equivalent Star will contain,

$$\therefore \quad R_1 = R_2 = R_3 = \frac{R \times R}{R+R+R} = \frac{R}{3}$$

- If all three resistances in a Star connection are of same magnitude say R, then its equivalent Delta contains all resistances of same magnitude of,

$$\therefore \quad R_{12} = R_{31} = R_{23} = R + R + \frac{R \times R}{R} = 3\,R$$

Q.11 Find equivalent resistance between A and B for the circuit shown in Fig. Q.11.1. **☞[SPPU : May-17, Marks 7]**

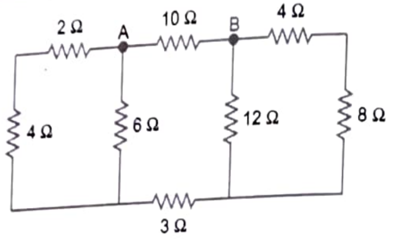

2 Ω
A
10 Ω
B
4 Ω
4 Ω
6 Ω
12 Ω
8 Ω
3 Ω

Fig. Q.11.1

Ans. : 2 Ω and 4 Ω are in series while 4 Ω and 8 Ω are in series as shown in the Fig. Q.11.1 (a).

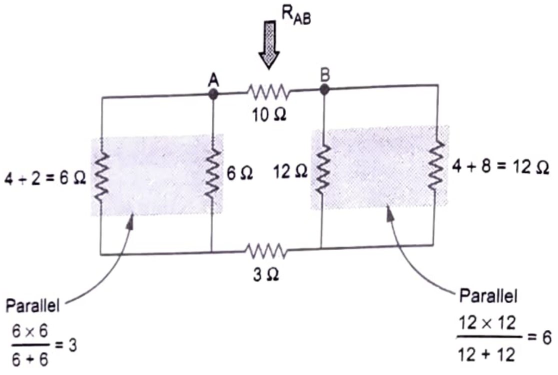

R_{AB}
A
B
10 Ω
4 + 2 = 6 Ω
6 Ω
12 Ω
4 + 8 = 12 Ω
3 Ω
Parallel
$\frac{6 \times 6}{6+6} = 3$
Parallel
$\frac{12 \times 12}{12+12} = 6$

Fig. Q.11.1 (a)

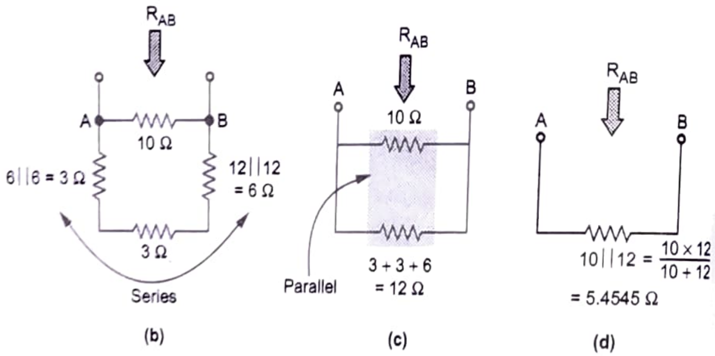

R_{AB}
A
B
10 Ω
6||6 = 3 Ω
12||12 = 6 Ω
3 Ω
Series
(b)
R_{AB}
A
B
10 Ω
Parallel
3 + 3 + 6 = 12 Ω
(c)
R_{AB}
A
B
$10||12 = \frac{10 \times 12}{10+12}$
= 5.4545 Ω
(d)

Fig. Q.11.1

$$R_{AB} = 5.4545\ \Omega$$

Q.12 Determine effective resistance between A and B.
☞ [SPPU : May-18, Marks 6]

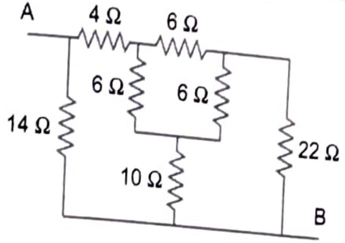

A
4 Ω
6 Ω
6 Ω
6 Ω
14 Ω
22 Ω
10 Ω
B

Fig. Q.12.1

Ans. : Convert 6 Ω delta to star. Each resistance in star is,

$$R' = \frac{6 \times 6}{6+6+6} = 2\ \Omega$$

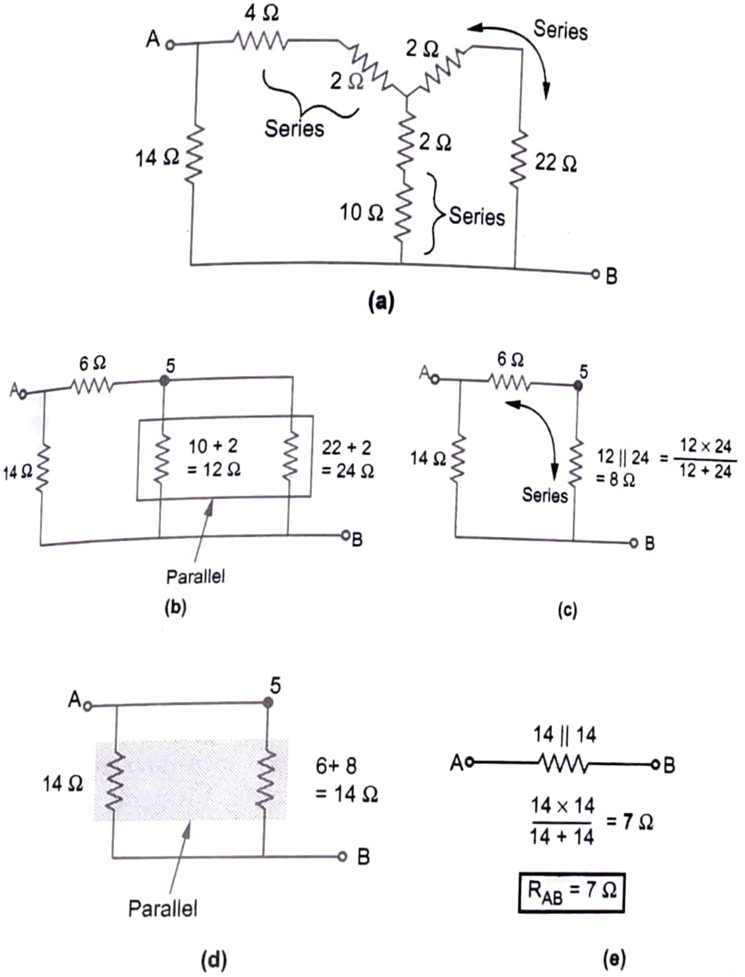

A
4 Ω
2 Ω
2 Ω
Series
Series
14 Ω
2 Ω
22 Ω
10 Ω
Series
B
(a)
A
6 Ω
5
14 Ω
10 + 2 = 12 Ω
22 + 2 = 24 Ω
Parallel
B
(b)
A
6 Ω
5
14 Ω
Series
12 || 24 = 8 Ω
$= \frac{12 \times 24}{12+24}$
B
(c)
A
5
14 Ω
6+ 8 = 14 Ω
Parallel
B
(d)
14 || 14
A
B
$\frac{14 \times 14}{14+14} = 7\ \Omega$
$R_{AB} = 7\ \Omega$
(e)

Fig. Q.12.1

5.6 : Loop Analysis

Q.13 List the various steps used for the loop analysis of a network.

Ans. : The various steps used for the loop analysis of a network are,

Step 1 : Choose the various loops.

Step 2 : Show the various loop currents and the polarities of associated voltage drops.

Step 3 : Before applying KVL, look for any current source. Analyse the branch consisting current source independently and express the current source value interms of assumed loop currents. Repeat this for all the current sources.

Step 4 : After the step 3, apply KVL to those **loops, which do not include any current source**. A loop cannot be defined through current source from KVL point of view. Follow the sign convention.

Step 5 : Solve the equations obtained in step 3 and step 4 simultaneously, to obtain required unknowns.

Important Points to Remember

- The voltage across **short circuit** is always zero though current flows through the short circuited path.
- The current through **open circuit** is always zero though there exists a voltage across open circuited terminals.
- If in a circuit there are branches or combinations of elements which do not carry any current then such branches and combinations are called **redundant** from circuit point of view and can be removed from the circuit.
- Any branch or combination across which there exists a short circuit, becomes redundant as it does not carry any current.
- If there is open circuit in a branch or combination, it can not carry any current and becomes redundant.

Q.14 Using Mesh/Loop analysis, calculate current flowing through R_{BC} for Fig. Q.14.1.

[SPPU : Dec.-15, Marks 6]

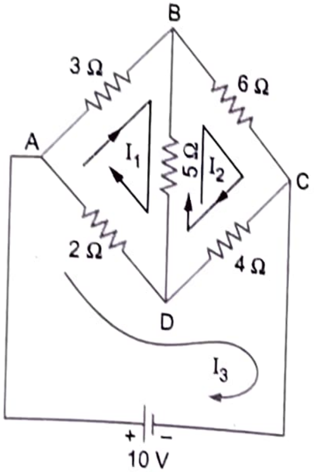


Fig. Q.14.1

Ans. : Step 1 : The various voltage drops and the polarities are shown in the Fig. Q.14.1 (a).

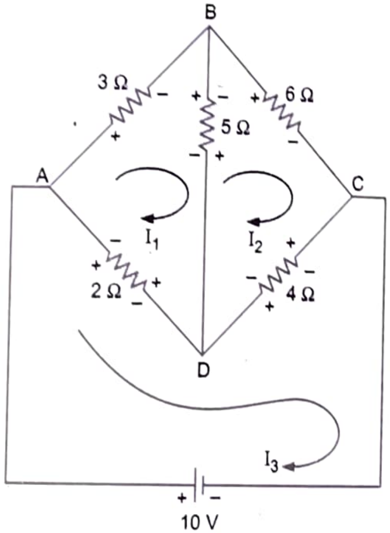


Fig. Q.14.1 (a)

Step 2 : Applying KVL to the three loops,

$-3I_1 - 5I_1 + 5I_2 - 2I_1 + 2I_3 = 0$ i.e. $-10I_1 + 5I_2 + 2I_3 = 0$ ...(1)

$-6I_2 - 4I_2 + 4I_3 - 5I_2 + 5I_1 = 0$ i.e. $5I_1 - 15I_2 + 4I_3 = 0$ ...(2)

$-2I_3 + 2I_1 - 4I_3 + 4I_2 + 10 = 0$ i.e. $2I_1 + 4I_2 - 6I_3 = -10$ ...(3)

Step 3 : Solving $I_1 = 1.111$ A, $I_2 = 1.111$ A, $I_3 = 2.777$ A

∴ $I_{BC} = I_2 =$ **1.111 A from B to C**

Q.15 Find current through branch AB using Kirchhoff's laws.

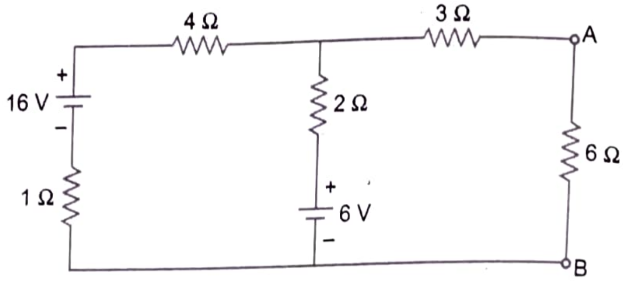

4 Ω
3 Ω
A
+
16 V
−
2 Ω
6 Ω
1 Ω
+
6 V
−
B

Fig. Q.15.1

Ans. : Step 1 : Show the various loop currents and polarities of drops as shown in the Fig. Q.15.1 (a).

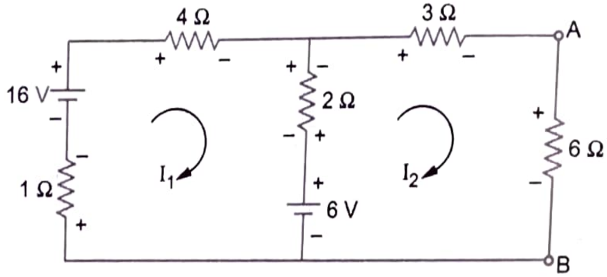

4 Ω
3 Ω
A
+
16 V
−
2 Ω
6 Ω
1 Ω
I_1
I_2
6 V
B

Fig. Q.15.1 (a)

Step 2 : Apply KVL to the two loops.

$$-4I_1 - 2I_1 + 2I_2 - 6 - I_1 + 16 = 0$$

i.e. $7I_1 - 2I_2 = 10$ ...(1)

$$-3I_2 - 6I_2 + 6 - 2I_2 + 2I_1 = 0$$

---

i.e. $-2I_1 + 11I_2 = 6$ ...(2)

Step 3 : Solving equations (1) and (2),

$I_1 = 1.6712$ A, $I_2 = 0.8493$ A

Step 4 : $I_{AB} = I_2 =$ **0.8493 A ↓**

Q.16 Determine all loop currents using KVL. All resistances are in ohm.

☞ **[SPPU : Dec.-17, Marks 6]**

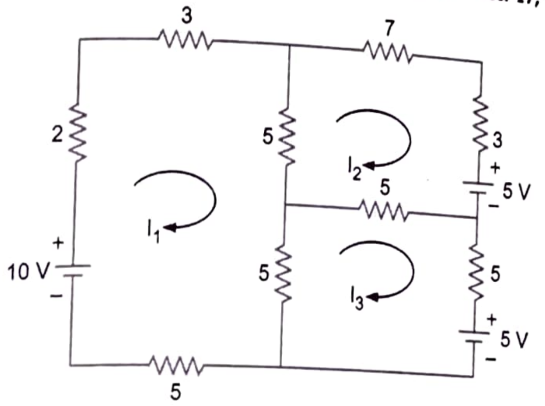

3
7
2
5
3
+
5 V
−
I_2
5
I_1
+
10 V
−
5
I_3
5
+
5 V
−
5

Fig. Q.16.1

Ans. : Show the polarities of voltage drops as shown in the Fig. Q.16.1 (a).

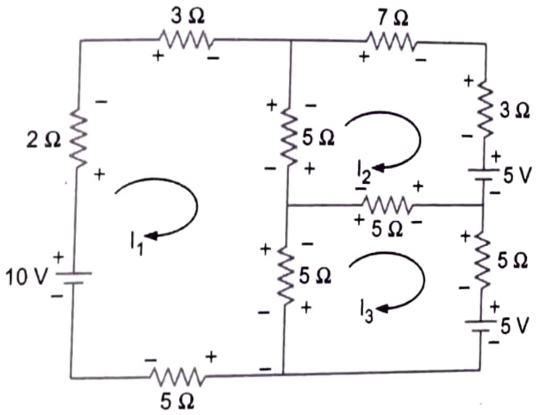

3 Ω
7 Ω
2 Ω
5 Ω
3 Ω
5 V
I_2
5 Ω
I_1
10 V
5 Ω
5 Ω
I_3
5 V
5 Ω

Fig. Q.16.1 (a)

Applying KVL,

$$-3I_1 - 5I_1 + 5I_2 - 5I_1 + 5I_3 - 5I_1 + 10 - 2I_1 = 0$$

$$\therefore \quad 2I_1 - 5I_2 - 5I_3 = 10 \qquad \ldots(1)$$

$$-7I_2 - 3I_2 - 5 - 5I_2 + 5I_3 - 5I_2 + 5I_1 = 0$$

$$\therefore \quad 5I_1 - 20I_2 + 5I_3 = 5 \qquad \ldots(2)$$

$$-5I_3 + 5I_2 - 5I_3 - 5 - 5I_3 + 5I_1 = 0$$

$$\text{i.e.} \quad 5I_1 + 5I_2 - 15I_3 = 5 \qquad \ldots(3)$$

Solving, I_1 = **0.3714 A**, I_2 = **– 0.2285 A**,

I_3 = **– 0.2857 A**

Negative sign indicates that the actual directions of I_2 and I_3 are opposite to those assumed in the given circuit.

Q.17 Find the current through branch AB using KVL. All resistances are in ohm. **[SPPU : Dec.-18, Marks 6]**

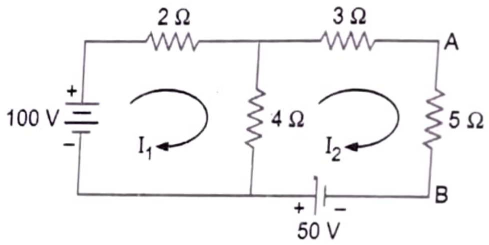


Fig. Q.17.1(a)

Ans. : The polarities are shown in the Fig. Q.17.1(b)

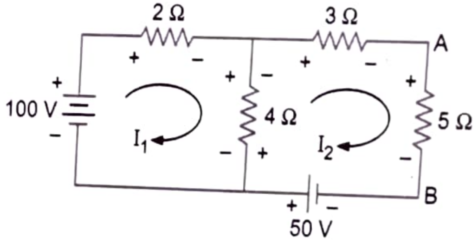


Fig. Q.17.1(b)

Applying KVL to two loops,

$$-2I_1 - 4I_1 + 4I_2 + 100 = 0 \quad \text{i.e.} \quad 6I_1 - 4I_2 = 100 \qquad \ldots(1)$$

$$-3I_2 - 5I_2 + 50 - 4I_2 + 4I_1 = 0 \quad \text{i.e.} \quad -4I_1 + 12I_2 = 50 \qquad \ldots(2)$$

Solving, I_1 = 25 A, I_2 = 12.5 A

∴ I_{AB} = I_2 = **12.5 A ↓**

Q.18 For the circuit shown in Fig. Q.18.1. Find the current flowing through PQ using Kirchhoff's laws. **[SPPU : May-19, Marks 6]**

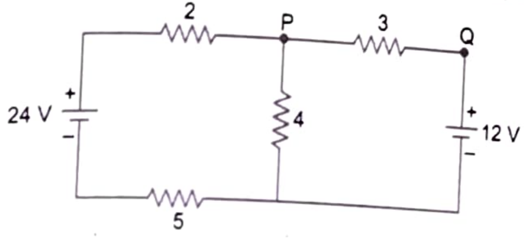


Fig. Q.18.1

Ans. : Step 1 : Show the loop currents.

Step 2 : Mark the polarities of voltage drops due to the loop currents as shown in in the Fig. Q.18.1 (a).

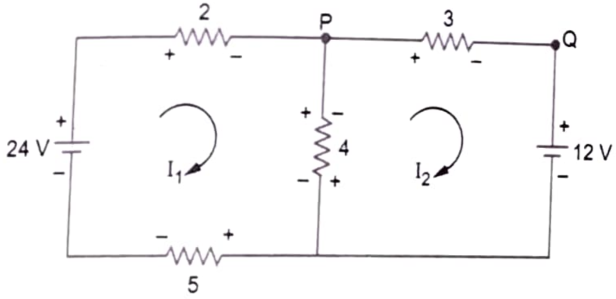


Fig. Q.18.1 (a)

Step 3 : Applying KVL to the two loops,

$$-2I_1 - 4I_1 + 4I_2 - 5I_1 + 24 = 0 \quad \text{i.e.} \quad 11I_1 - 4I_2 = 24 \qquad \ldots(1)$$

$$-3I_2 - 12 - 4I_2 + 4I_1 = 0 \quad \text{i.e.} \quad +4I_1 - 7I_2 = 12 \qquad \ldots(2)$$

Step 4 : Solving equation (1) and (2),

$$I_1 = 1.9672 \text{ A}, \; I_2 = -0.5901 \text{ A} \rightarrow$$

Negative sign indicates that the direction of I_2 is opposite to that assumed.

$$\therefore \quad I_{PQ} = I_2 = +0.5901 \text{ A} \quad \text{i.e. Q to P}$$

5.7 : Superposition Theorem

Q.19 State and explain Superposition theorem.

☞ [SPPU : Dec.-05, 06, 10,13,18, May-05, 07, 09, 10,15, Marks 6]

Ans. : The statement of the theorem is,

Statement : In any multisource complex network consisting of linear bilateral elements, the voltage across or current through any given element of the network is equal to the algebraic sum of the individual voltages or currents, produced independently across or in that element by each source acting independently, when all the remaining sources are replaced by their respective internal resistances.

If the internal resistances of the sources are unknown then the **independent voltage sources** must be replaced by **short circuit** while the **independent current sources** must be replaced by an open circuit.

Explanation :

Consider a network, shown in the Fig. Q.19.1, having two voltage sources V_1 and V_2. Calculate, the current in branch A-B of the network, using superposition theorem.

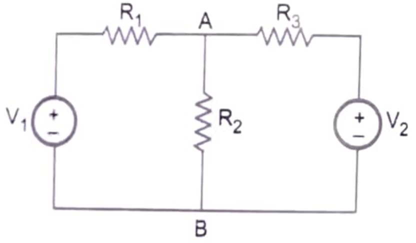


Fig. Q.19.1

Step 1 : According to Superposition theorem, consider each source independently.

- Let source V_1 volts is acting independently. At this time, other sources must be replaced by internal impedances.
- But as internal impedance of V_2 is not given, the source V_2 must be replaced by short circuit. Hence circuit becomes, as shown in the Fig. Q.19.1 (a).
- Using any of the network reduction techniques discussed earlier, obtain the current through branch A-B i.e. I_{AB} due to source V_1 alone.

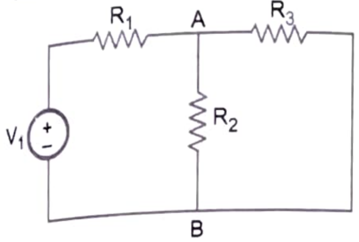


Fig. Q.19.1 (a)

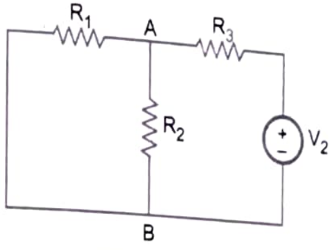


Fig. Q.19.1 (b)

Step 2 : Now consider source V_2 volts alone, with V_1 replaced by a short circuit, to obtain the current through branch A-B.

- The corresponding circuit is shown in the Fig. Q.19.1 (b).
- Obtain I_{AB} due to V_2 alone, by using any of the network reduction techniques.

Step 3 : According to the Superposition theorem, the total current through branch A-B is the sum of the currents through branch A-B produced by each source acting independently.

$$\therefore \quad \text{Total } I_{AB} = I_{AB} \text{ due to } V_1 + I_{AB} \text{ due to } V_2$$

Steps to Apply Superposition Theorem

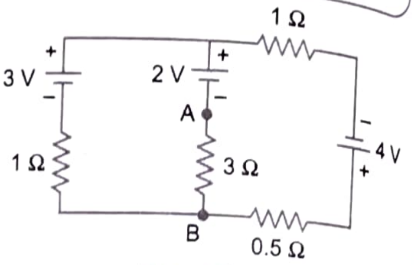
Step 1 : Select a single source acting alone. Short the other voltage sources and open the current sources, if internal resistances are not known. If known, replace them by their internal resistances.

Step 2 : Find the current through or the voltage across the required element, due to the source under consideration, using a suitable network simplification technique.

Step 3 : Repeat the above two steps for all the sources.

Step 4 : Add the individual effects produced by individual sources, to obtain the total current in or voltage across the element.

Q.20 Apply superposition theorem to calculate current flowing in 3 Ω resistance for the network. **☞[SPPU : May-14, Marks 7]**



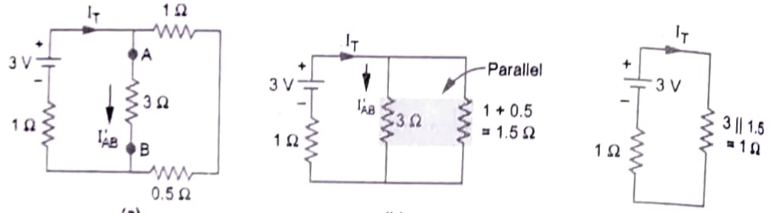
3 V
+
−
2 V
+
−
1 Ω
A
3 Ω
B
−
4 V
+
1 Ω
0.5 Ω

Fig. Q.20.1

Ans. : Step 1 : Consider 3 V alone, short other two sources.

From Fig. Q.20.1 (c) ,

$$I_T = \frac{3}{1+1} = 1.5 \text{ A}$$



I_T
1 Ω
+
3 V
−
A
3 Ω
1 Ω
I'_{AB}
B
0.5 Ω
I_T
3 V
I'_{AB}
3 Ω
Parallel
1 + 0.5
= 1.5 Ω
1 Ω
I_T
+
3 V
−
1 Ω
3 || 1.5
= 1 Ω

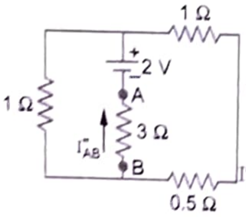
(a) (b) (c)

Fig. Q.20.1 (a)

Using current division rule to the Fig. Q.20.1 (b),

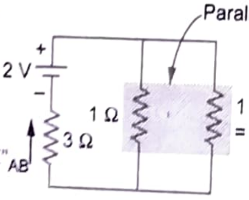
$$I'_{AB} = \frac{I_T \times 1.5}{3+1.5} = \frac{1.5 \times 1.5}{4.5} = 0.5 \text{ A} \downarrow$$

Step 2 : Consider 2 V source alone, short other sources



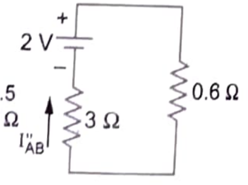
1 Ω
+
2 V
−
A
1 Ω
3 Ω
I'_{AB}
B
0.5 Ω

Fig. Q.20.1 (d)



2 V
+
−
3 Ω
I''_{AB}
1 Ω
Parallel
1 + 0.5
= 1.5 Ω

Fig. Q.20.1 (e)



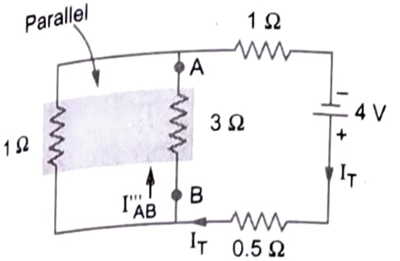
+
2 V
−
I''_{AB}
3 Ω
0.6 Ω

Fig. Q.20.1 (f)

∴

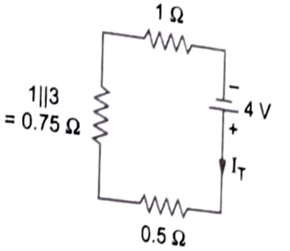
$$I''_{AB} = \frac{2}{3+0.6} = 0.555 \text{ A} \uparrow$$

Step 3 : Consider 4 V source alone, short other sources



Parallel
1 Ω
A
3 Ω
−
4 V
+
1 Ω
I_T
I'''_{AB}
B
I_T
0.5 Ω

Fig. Q.20.1 (g)



1 Ω
1||3
= 0.75 Ω
−
4 V
+
I_T
0.5 Ω

Fig. Q.20.1 (h)

∴

$$I_T = \frac{4}{1+0.5+0.75} = 1.777 \text{ A}$$

∴ Using current division rule to the Fig. Q.20.1 (g),

$$I'''_{AB} = \frac{I_T \times 1}{1+3} = 0.444 \text{ A} \uparrow$$

Step 4 :

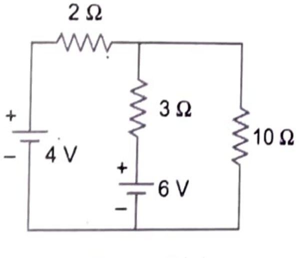
$$I_{AB} = I'_{AB} + I''_{AB} + I'''_{AB}$$

$$= (0.5 \text{ A} \downarrow) + (0.555 \text{ A} \uparrow) + (0.444 \text{ A} \uparrow)$$

∴

$$= (0.5 \text{ A} \downarrow) + (1 \text{ A} \uparrow) = 0.5 \text{ A} \uparrow = I_{3\Omega}$$

Q.21 Apply superposition theorem, to the circuit shown in Fig. Q.21.1 to calculate current flowing in 10 Ω resistance. **☞ [SPPU : Dec.-14, Marks 6]**



2 Ω
+
−
4 V
3 Ω
+
6 V
−
10 Ω

Fig. Q.21.1

Ans. : Step 1 : Consider 4 V source, short 6 V.

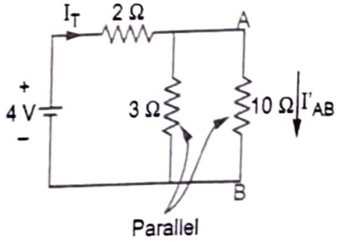

I_T
2 Ω
A
+
4 V
–
3 Ω
10 Ω
I'_{AB}
B
Parallel

Fig. Q.21.1 (a)

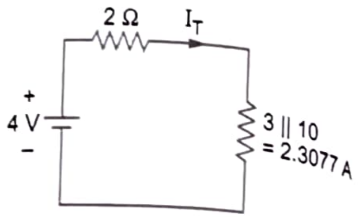

2 Ω
I_T
+
4 V
–
3 || 10
= 2.3077 A

Fig. Q.21.1 (b)

$$\therefore \qquad I_T = \frac{4}{2+2.3077} = 0.92857 \text{ A}$$

... Refer Fig. Q.21.1 (b)

Using current distribution rule to the Fig. Q.21.1 (a),

$$I'_{AB} = \frac{I_T \times 3}{(3+10)} = \frac{0.92857 \times 3}{13} = \mathbf{0.21428 \ A} \downarrow$$

... Due to 4 V

Step 2 : Consider 6 V source, short 4 V.

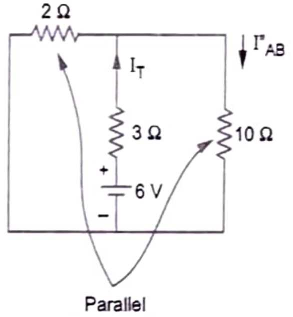

2 Ω
I''_{AB}
I_T
3 Ω
10 Ω
+
6 V
–
Parallel

Fig. Q.21.1 (c)

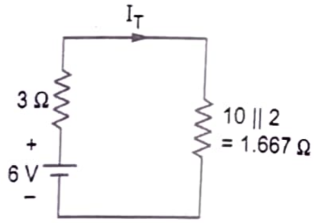

I_T
3 Ω
+
6 V
–
10 || 2
= 1.667 Ω

Fig. Q.21.1 (d)

$$\therefore \qquad I_T = \frac{6}{3+1.667} = 1.28571 \text{ A}$$

Using current distribution rule to the Fig. Q.21.1 (c),

$$I''_{AB} = \frac{I_T \times 2}{(2+10)} = \frac{12857 \times 2}{12} = \mathbf{0.21428 \ A} \downarrow$$

... Due to 6 V

Step 3 :

$$I_{10\,\Omega} = I'_{AB} + I''_{AB} = 0.21428 \text{ A} \downarrow + 0.21428 \text{ A} \downarrow = 0.42857 \text{ A} \downarrow$$

Q.22 Calculate the current through all resistance using superposition principle.

☞ **[SPPU : Dec.-17, May-18, Marks : 6]**

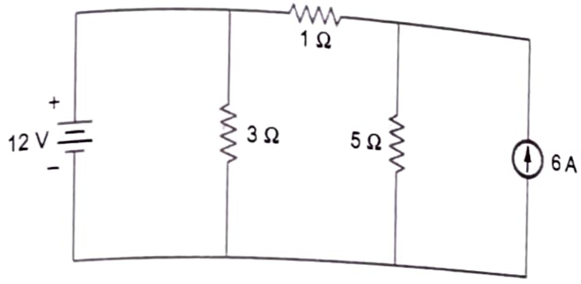

1 Ω
+
12 V
–
3 Ω
5 Ω
6 A

Fig. Q.22.1

Ans. : Step 1 : Consider 12 V alone, open 6 A source.

Applying KVL to the Fig. Q.22.1(a).

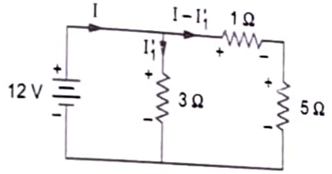

I
$I - I'_1$
1 Ω
I'_1
12 V
3 Ω
5 Ω

Fig. Q.22.1 (a)

$$-3I'_1 + 12 = 0$$

$$\therefore \qquad I'_1 = \mathbf{4 \ A} \downarrow$$

$$-(I-I'_1) - 5(I-I'_1) + 3I'_1 = 0$$

$$\therefore \qquad I = 6 \text{ A}$$

Current through 1 Ω and 5 Ω = $I - I'_1$ = **2 A**

Step 2 : Consider 6 A, short 12 V source

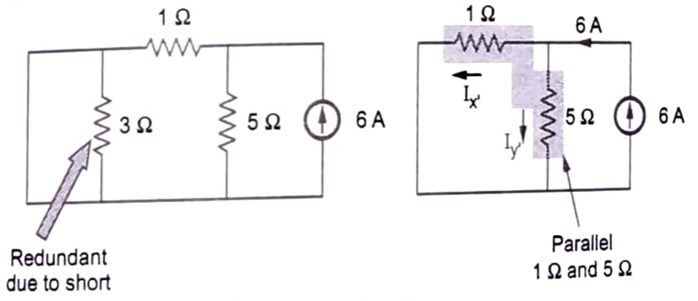

1 Ω
3 Ω
5 Ω
6 A
Redundant
due to short
1 Ω
6 A
$I_{x'}$
$I_{y'}$
5 Ω
6 A
Parallel
1 Ω and 5 Ω

Fig. Q.22.1 (b)

Using current distribution rule,

$$I'_x = 6\times\frac{5}{5+1} = 5\text{ A},\ I'_y = 6\times\frac{1}{5+1} = 1\text{ A},\ I''_{3\Omega} = 0\text{ A}$$

Step 3 :

$$I_{3\Omega} = I'_1 + I''_{3\Omega} = 4\text{ A} + 0\text{ A} = 4\text{ A}\downarrow$$

$$I_{1\Omega} = 2\text{A}\rightarrow + I'_x\leftarrow = 2\text{A}\rightarrow + 5\text{A}\leftarrow = 3\text{ A}\leftarrow$$

$$I_{5\Omega} = 2\text{A}\downarrow + I'_y\downarrow = 2\text{A}\downarrow + 1\text{A}\downarrow = 3\text{ A}\downarrow$$

5.8 : Thevenin's Theorem

Q.23 State and explain Thevenin's theorem.

☞ [SPPU : Dec.-05, 12, 15, 17, May-08, 11, 14, 16, Marks 6]

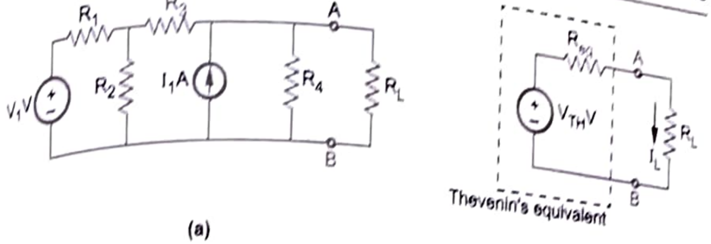
Ans. : The statement of the theorem is,

Let us see the statement of the theorem.

> **Statement :** Any combination of linear bilateral circuit elements and active sources, regardless of the connection or complexity, connected to a given load R_L, may be replaced by a simple two terminal network consisting of a single voltage source of V_{TH} volts and a single resistance R_{eq} in series with the voltage source, across the two terminals of the load R_L. The voltage V_{TH} is the open circuit voltage measured at the two terminals of interest, with load resistance R_L removed. This voltage is also called **Thevenin's equivalent voltage**. The R_{eq} is the **equivalent resistance** of the given network as viewed through the terminals where R_L is connected, but with R_L removed and all the active sources are replaced by their internal resistances.
>
> If the internal resistances are not known then **independent voltage sources** are to be replaced by the **short circuit** while the **independent current sources** must be replaced by the **open circuit**.

Explanation :

- The concept of Thevenin's equivalent across the terminals of interest can be explained by considering the circuit shown in the Fig. Q.23.1(a).

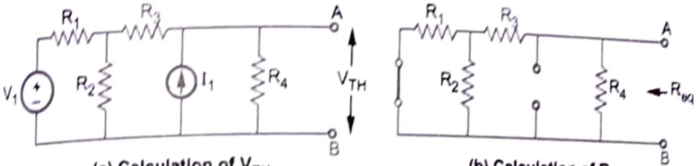


(a)

(b)

Fig. Q.23.1

- The terminals A-B are the terminals of interest across which R_L is connected. Then Thevenin's equivalent across the load terminals A-B can be obtained as shown in the Fig. Q.23.1 (b).
- The voltage V_{TH} is obtained across the terminals A-B with R_L removed. Hence V_{TH} is also called open circuit Thevenin's voltage.
- The circuit to be used to calculate V_{TH} is shown in the Fig. Q.23.2 (a), for the network considered above.



(a) Calculation of V_{TH}

(b) Calculation of R_{eq}

Fig. Q.23.2

- While R_{eq} is the equivalent resistance obtained as viewed through the terminals A-B with R_L removed, voltage sources replaced by short circuit and current sources by open circuit. This is shown in the Fig. Q.23.2 (b).
- While obtaining V_{TH}, any of the network simplification techniques can be used.
- When the circuit is replaced by Thevenin's equivalent across the load resistance, then the load current can be obtained as,

$$\boxed{I_L = \frac{V_{TH}}{R_L + R_{eq}}}$$

- By using this theorem, current through any branch of the circuit can be obtained, treating that branch resistance as the load resistance and obtaining Thevenin's equivalent across the two terminals of that branch.

Q.24 Explain the steps to apply Thevenin's theorem to obtain Thevenin's equivalent circuit.

☞ [SPPU : Dec.-18, May-19, Marks 6]

Ans. :

Step 1 : Remove the branch resistance through which current is to be calculated.

Step 2 : Calculate the voltage across these open circuited terminals, by using any of the network simplification techniques. This is V_{TH}.

Step 3 : Calculate R_{eq} as viewed through the two terminals of the branch from which current is to be calculated by removing that branch resistance and replacing all independent sources by their internal resitances. If the internal reistances are not known then replace independent voltage sources by short circuits and independent current sources by open circuits.

Step 4 : Draw the Thevenin's equivalent showing source V_{TH}, with the resistance R_{eq} in series with it, across the terminals of branch of interest.

Step 5 : Reconnect the branch resistance. Let it be R_L. The required current through that branch is given by,

$$I = \frac{V_{TH}}{R_{eq} + R_L}$$

Q.25 Apply Thevenin's theorem to calculate current flowing in 5 Ω resistance for the network.

☞[SPPU : Dec.-16, Marks 7]

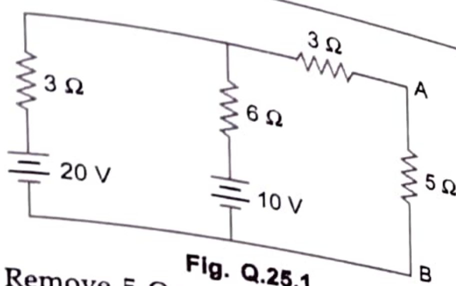


Fig. Q.25.1

Ans. : Step 1 : Remove 5 Ω resistance.

Step 2 : Find open circuit voltage.

$$V_{AB} = V_{TH}$$

Apply KVL to the loop,

$$-6 I_1 - 10 + 20 - 3 I_1 = 0$$

i.e. $$I_1 = 1.111 \text{ A}$$

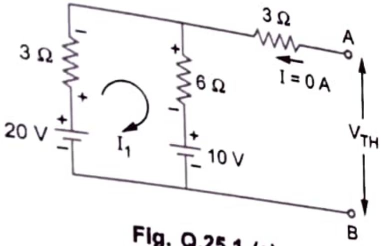


Fig. Q.25.1 (a)

Tracing path AB as shown in the Fig. Q.25.1 (b).

$$\therefore V_{AB} = V_{TH} = 6.666 + 10$$

$$= \mathbf{16.666 \text{ V}}$$

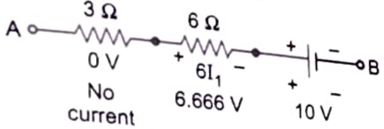
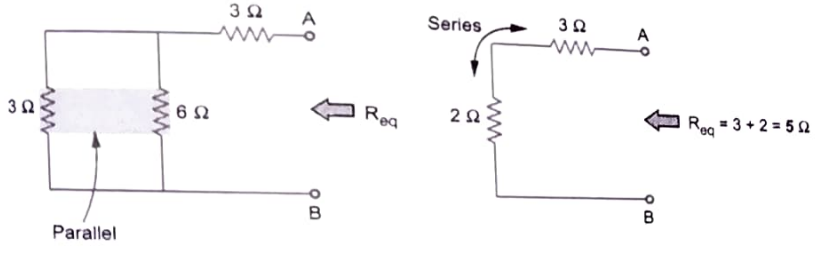


Fig. Q.25.1 (b)

Step 3 : Find R_{eq}, shorting voltage sources as shown in the Fig. Q.25.1 (c)



(c) (d)

Fig. Q.25.1

Step 4 : Thevenin's equivalent is shown in the Fig. Q.25.1 (e).

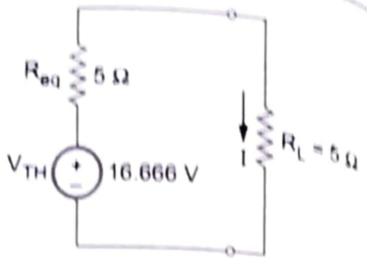


Fig. Q.25.1 (e)

Step 5 :

$$I = \frac{V_{TH}}{R_{eq} + R_L}$$

$$= \frac{10.666}{5+5}$$

$$= \mathbf{1.6666\ A} \downarrow$$

Q.26 Apply Thevenin's theorem, to calculate current flowing in 10 ohm resistance, for the circuit shown in Fig. Q.26.1.

☞[SPPU : Dec.-14, Marks 7]

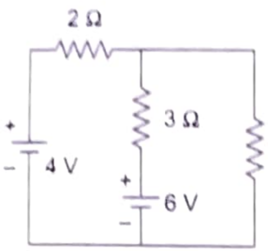


Fig. Q.26.1

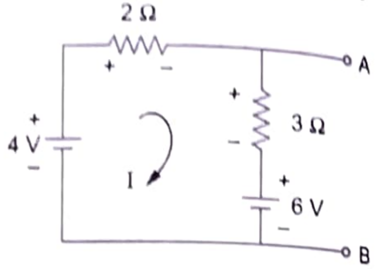


Fig. Q.26.1 (a)

Ans. : Step 1 : Remove 10 Ω resistor

Step 2 : Find $V_{TH} = V_{AB}$ shown in the Fig. Q.26.1 (a).

Applying KVL,

$$-2\,I - 3\,I - 6 + 4 = 0$$

$$\therefore \quad I = -0.4\ A$$

Trace the path A – B as shown in the Fig. Q.26.1 (b).

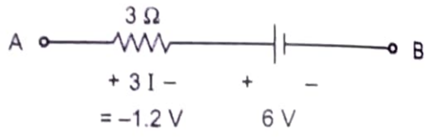


Fig. Q.26.1 (b)

$$\therefore \quad V_{TH} = V_{AB}$$

$$= -1.2 + 6$$

$$= \mathbf{4.8\ V\ with\ A\ positive}$$

Step 3 : Find R_{eq}, shorting voltage sources.

$$R_{eq} = 3\,\Omega \parallel 2\,\Omega$$

$$\therefore \quad = \frac{3\times 2}{3+2} = \mathbf{1.2\ \Omega}$$

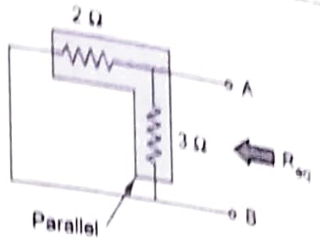


Fig. Q.26.1 (c)

Step 4 : Thevenin's equivalent is shown in the Fig. Q.26.1(d).

$$\therefore \quad I = \frac{V_{TH}}{R_{eq} + R_L} = \frac{4.8}{12 + 10}$$

$$\therefore \quad = \mathbf{0.42857\ A} \downarrow = I_{10\Omega}$$

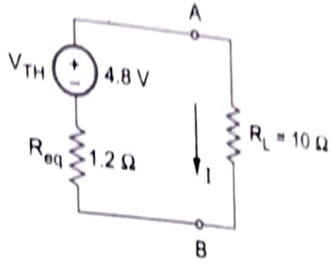


Fig. Q.26.1 (d)

Q.27 Using Thevenin's theorem, determine the value of current flowing through 6 Ω resistance.

☞[SPPU : May-15, Marks 7]

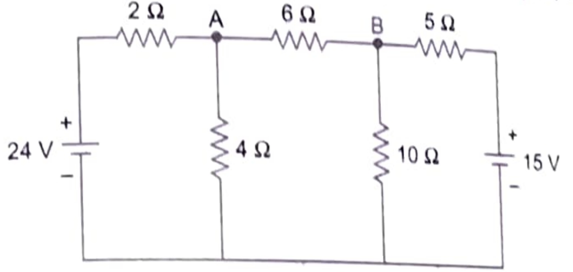


Fig. Q.27.1

Ans. : Step 1 : Remove branch AB.

Step 2 : Find open circuit voltage $V_{TH} = V_{AB}$,

Applying KVL to the two loops in the Fig. Q.27.1 (a),

$-2I_1 - 4I_1 + 24 = 0$ i.e. $I_1 = 4\ A$

$-5I_2 - 10I_2 + 15 = 0$ i.e. $I_2 = 1\ A$

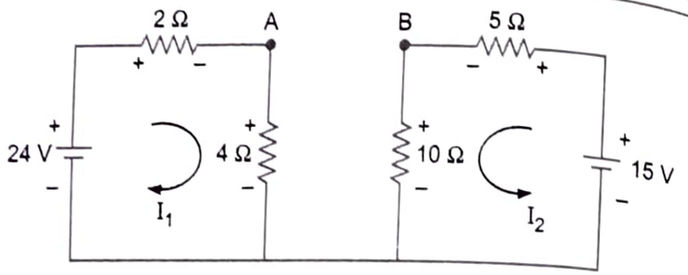


Fig. Q.27.1(a)

From Fig. Q.27.1 (b),

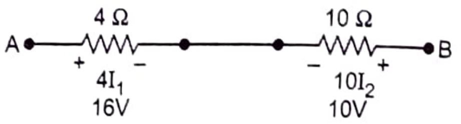
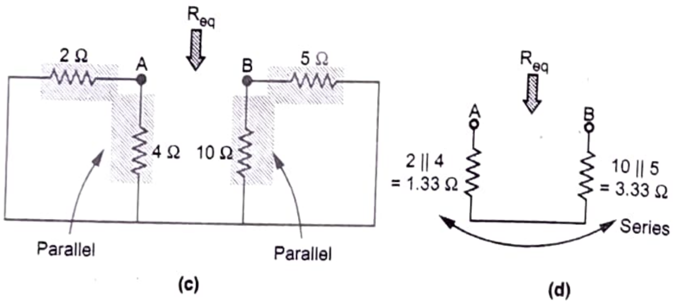


Fig. Q.27.1 (b)

$$V_{TH} = V_{AB} = 16 - 10 = \mathbf{6\ V} \qquad \text{with 'A' + ve}$$

Step 3 : Find $R_{eq} = R_{TH}$ replacing all voltage sources by short circuit.



(c) (d)

Fig. Q.27.1

$$R_{eq} = 1.333 + 3.333 = \mathbf{4.667\ \Omega}$$

Step 4 : The Thevenin's equivalent is shown in the Fig. Q.27.1 (e).

Step 5 :
$$I = \frac{V_{TH}}{R_L + R_{eq}}$$

$$= \frac{6}{6 + 4.667} = \mathbf{0.5625 A \downarrow}$$

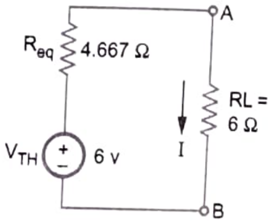


Fig. Q.27.1 (e)

END...

UNIT - VI

6 Work, Power, Energy and Batteries

Section A : Work, Power and Energy

6.1 : Effect of Temperature on Resistance

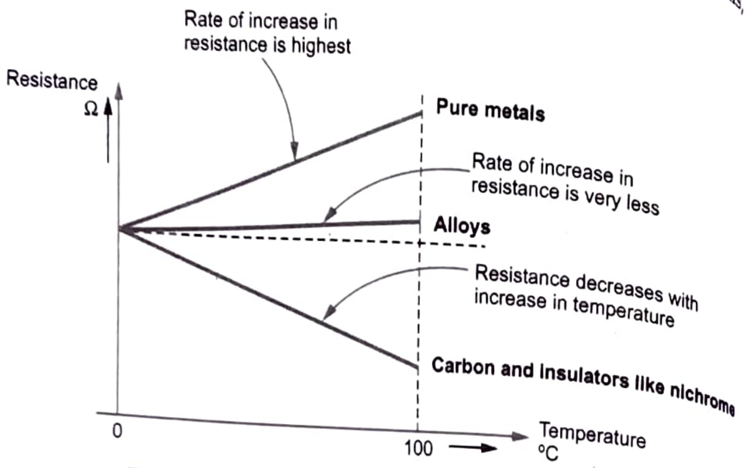
Q.1 Discuss the effect of temperature on the resistance of various materials with the help of a graph.

[SPPU : Dec.-03, 15, May-04, 06, 07, 18, 19, Marks 4]

Ans. : The resistance of all the pure metals like copper, iron, tungsten etc. **increases linearly with temperature in the range of 0 °C to 100 °C.**

- For a copper, its resistance is 100 Ω at 0° then it increases linearly upto 100 °C. At a temperature of – 234.5 °C it is almost zero.
- Resistance of carbon and insulators like rubber, paper and all electrolyts, **decreases as the temperature increases.**
- In carbon and insulators, due to increase in temperature, few electrons from atoms gain extra energy and made available as free electrons.
- So as number of free electrons increases, overall difficulty to the flow of electrons reduces which causes decrease in resistance.
- The resistance of alloys increases as the temperature increases but rate of increase is not significant. In fact the alloys like Manganin (alloy of copper, managanese and nickel), Eureka (alloy of copper and nickel) etc. show almost no change in resistance for considerable change in the temperature. Due to this property alloys are used to manufacture the resistance boxes.

- The Fig. Q.1.1 shows the effect of temperature on metals, insulating materials and alloys.



Some alloys show constant resistance characteristics

Fig. Q.1.1 Effect of temperature on resistance

Q.2 What is semiconductor ? Give two examples. Explain the effect of temperature on semiconductors.

☞ [SPPU : May-04, 07,10, Dec.-05, Marks 3]

Ans. : The materials having conductivity between that of metals and insulators are called semiconductors. The examples are silicon, germanium etc.

- At absolute zero temperature, the semiconductors behave as perfect insulators i.e. their resistance is very high.
- As temperature increases, the resistance of the semoconductors decreases with fast rate as shown in the Fig. Q.2.1.
- At higher temperature, more valence electrons acquire the energy and become free electrons. Due to increased number of free electrons, resistance of semiconductors decreases as temperature increases.

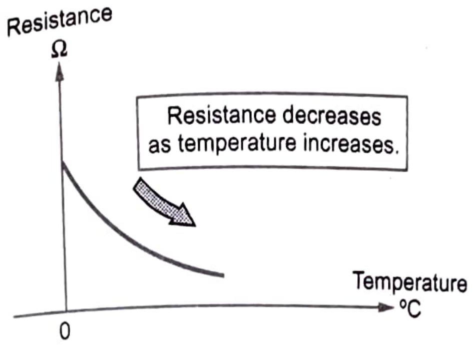


Fig. Q.2.1 Effect of temperature on semiconductors

- **Semiconductors have negative temperature coefficient of resistivity** hence as temperature increases, their resistance decreases.

6.2 : Resistance Temperature Coefficient (R.T.C.)

Q.3 Define temperature coefficient of resistance and state its unit. State the factors on which it depends.

☞ [SPPU : Dec.-03, 14, May-04, 06, 08, 12, Marks 4]

Ans. :

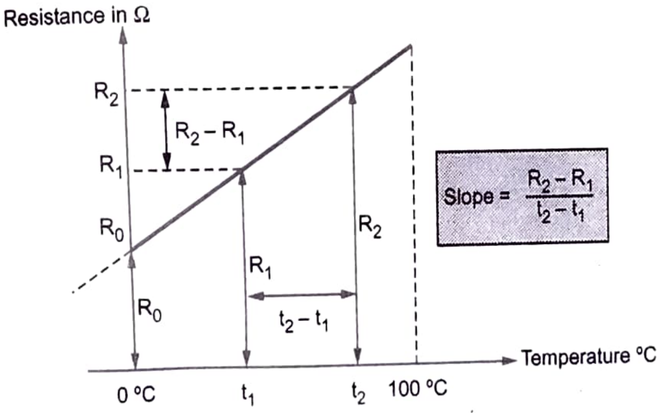


Fig. Q.3.1 Graph of resistance against temperature

Consider a conductor, the resistance of which increases with temperature linearly as shown in the Fig. Q.3.1.

Let, R_0 = Initial resistance at 0 °C

R_1 = Resistance at t_1 °C

R_2 = Resistance at t_2 °C

Definition of R.T.C. : The resistance temperature coefficient at t °C is the ratio of change in resistance per degree celcius to the resistance at t °C. It is denoted as α.

$$\text{R.T.C. at t °C} = \frac{\Delta R \text{ per °C}}{R_t} = \alpha_t$$

- From the Fig. Q.6.1, change in resistance = $R_2 - R_1$ while change in temperature = $t_2 - t_1$

$\therefore$ Change in resistance per °C = $\dfrac{\Delta R}{\Delta t} = \dfrac{R_2 - R_1}{t_2 - t_1}$

- Hence according to the definition of R.T.C. we can write α_1 i.e. R.T.C. at t_1 °C as,

$$\alpha_1 = \frac{\text{Change in resistance per °C}}{\text{Resistance at } t_1 \text{ °C}} = \frac{(R_2 - R_1 / t_2 - t_1)}{R_1}$$

- Similarly R.T.C. at 0 °C i.e. α_0 can be written as

$$\alpha_0 = \frac{(R_1 - R_0 / t_1 - 0)}{R_0}$$

Thus unit of R.T.C. is **per degree celcius** i.e. /°C.

- R.T.C. depends on, 1. Initial resistance of the material 2. Change in temperature 3. Nature of the material

Q.4 Prove that $R_2 = R_1 [1 + \alpha_1 \Delta t]$.

Ans. : Let R_1 = Resistance at t_1 °C and R_t = Resistance at t °C

$$\alpha_1 = \frac{(R_t - R_1 / t - t_1)}{R_1} \quad \text{... from definition}$$

$\therefore \alpha_1 R_1 (t - t_1) = R_t - R_1$ i.e. $R_t = R_1 [1 + \alpha_1 (t - t_1)]$

Where $t - t_1$ = Change in temperature = Δt

- In general above result can be expressed as,

$R_{final} = R_{initial} [1 + \alpha_{initial} (\Delta t)]$

- So if initial temperature is t_1 and final is t_2, we can write,

$$\therefore \quad \boxed{R_2 = R_1 [1 + \alpha_1 \Delta t]}$$

Thus knowing resistance and R.T.C. of the material at any one temperature, the resistance of material at any other temperature can be obtained.

Q.5 With usual notations, obtain the expression $\alpha_2 = \dfrac{\alpha_1}{1 + \alpha_1(t_2 - t_1)}$

and hence obtain $\alpha_t = \dfrac{\alpha_0}{1 + \alpha_0 \cdot t}$ and then $\alpha_0 = \dfrac{\alpha_1}{1 - \alpha_1 \cdot t}$.

OR Prove that $(\alpha_1 - \alpha_2) = \alpha_1 \alpha_2 (t_2 - t_1)$

OR Prove that : $\dfrac{\alpha_1}{\alpha_2} = 1 + \alpha_1 (t_2 - t_1)$.

☞ [SPPU : Dec.-04,05,06,07,10,11,12,16, May-07,08,09,10,11,14, Marks 6]

Ans. : It is known that if the resistance and R.T.C. of the material at any one temperature is available, then resistance of material at any other temperature can be obtained as,

$$R_2 = R_1 [1 + \alpha_1 (t_2 - t_1)] \quad \text{... (1)}$$

where R_1 and α_1 are resistance and R.T.C. at t_1 °C and R_2 is resistance at t_2 °C.

- If the same resistance is cooled from t_2 to t_1 °C and if α_2 is R.T.C. at t_2 °C then,

$$R_1 = R_2 [1 + \alpha_2 (t_1 - t_2)] \quad \text{... (2)}$$

- Dividing equation (1) by R_2,

$$\therefore \qquad 1 = \frac{R_1}{R_2}\left[1+\alpha_1(t_2-t_1)\right] \quad \text{i.e.} \quad \frac{R_2}{R_1} = 1+\alpha_1(t_2-t_1) \qquad \dots (3)$$

- Dividing equation (2) by R_1,

$$1 = \frac{R_2}{R_1}\left[1+\alpha_2(t_1-t_2)\right] \quad \text{i.e.} \quad \frac{R_2}{R_1} = \frac{1}{1+\alpha_2(t_1-t_2)} \qquad \dots (4)$$

- Equating (3) and (4) we can write,

$$1+\alpha_1(t_2-t_1) = \frac{1}{1+\alpha_2(t_1-t_2)}$$

$$\text{i.e. } \alpha_1(t_2-t_1) = \frac{1}{1+\alpha_2(t_1-t_2)} - 1 = \frac{1-1-\alpha_2(t_1-t_2)}{1+\alpha_2(t_1-t_2)}$$

$$\therefore \qquad \alpha_1(t_2-t_1) = \frac{-\alpha_2(t_1-t_2)}{1+\alpha_2(t_1-t_2)} = \frac{\alpha_2(t_2-t_1)}{1+\alpha_2(t_1-t_2)}$$

$$\boxed{\begin{aligned} \therefore \quad \alpha_1 &= \frac{\alpha_2}{1+\alpha_2(t_1-t_2)} = \frac{1}{\frac{1}{\alpha_2}+(t_1-t_2)} \\ \text{or} \quad \alpha_2 &= \frac{\alpha_1}{1+\alpha_1(t_2-t_1)} = \frac{1}{\frac{1}{\alpha_1}+(t_2-t_1)} \end{aligned}} \qquad \dots (5)$$

- Rearraning the terms it can be proved that $(\alpha_1 - \alpha_2) = \alpha_1\alpha_2(t_2 - t_1)$.
- If starting temperature is $t_1 = 0$ °C, $\alpha_1 = \alpha_0$, $t_2 = t$ °C, and $\alpha_2 = \alpha_t$ at $t_2 = t$ °C is required then we can write,

$$\boxed{\begin{aligned} \therefore \quad \alpha_0 &= \frac{\alpha_t}{1+\alpha_t(0-t)} \quad \text{i.e.} \quad \alpha_t(1+\alpha_0 t) = \alpha_0 \\ \text{i.e. } \alpha_t &= \frac{\alpha_0}{1+\alpha_0 t} \end{aligned}}$$

- From equation (5) it can be proved that $\frac{\alpha_1}{\alpha_2} = 1 + \alpha_1(t_2 - t_1)$.

Important Points to Remember

- Similar to the resistance, the specific resistance or resistivity (ρ) also is a function of temperature.
- Thus if ρ_1 = resistivity at t_1 °C and ρ_2 = resistivity at t_2 °C then temperature coefficient of resistivity at t_1 °C can be defined as,

$$\alpha_{t1} = \frac{(\rho_2-\rho_1)/(t_2-t_1)}{\rho_1} \quad \text{and} \quad \rho_t = \rho_0(1+\alpha_0 t)$$

$$\therefore \quad \text{and} \quad \rho_{t2} = \rho_{t1}\left[1+\alpha_{t1}(t_2-t_1)\right]$$

Q.6 A coil has a resistance of 40 Ω at 25 °C. When its temperature is increased to 110 °C the resistance increases to 50 Ω. Calculate the temperature coefficient of resistance of coil material at i) 25 °C ii) 110 °C and iii) 0 °C.

☞ [SPPU : May-11, Marks 6]

Ans. : $R_1 = 40\ \Omega$, $t_1 = 25$ °C, $R_2 = 50\ \Omega$, $t_2 = 110$ °C

$$R_2 = R_1[1+\alpha_1 \Delta t] \quad \text{i.e.} \quad 50 = 40[1+\alpha_1(110-25)]$$

i) $\alpha_1 = 0.00294$ / °C at $t_1 = 25$ °C

ii)
$$\alpha_2 = \frac{1}{\frac{1}{\alpha_1}+(t_2-t_1)} = \frac{1}{\frac{1}{0.00294}+(110-25)}$$

$$= 0.002352 \text{ /°C at } t_2 = 110 \text{ °C}$$

iii)
$$\alpha_t = \frac{\alpha_0}{1+\alpha_0 t} \quad \text{i.e.} \quad 0.00294 = \frac{\alpha_0}{1+\alpha_0 \times 25}$$

$$\therefore \qquad \alpha_0 = 0.003173 \text{ / °C}$$

Q.7 A filament lamp has a normal rating of 240 V, 60 W. If switched on at the room temperature of 20 °C to the 240 V supply, it draws an initial current of 2.5 A, calculate the temperature of filament in normal hot condition, if the temperature coefficient of resistance at 20 °C is 0.0055 per °C.

☞ [SPPU : Dec.-18, Marks 7]

Ans. : V = 240 V, P = 60 W, $t_1 = 20$ °C, $\alpha_1 = 0.0055$/°C

R_2 = Resistance of filament in ON condition

$$= \frac{V^2}{P} = \frac{240^2}{60} = 960\,\Omega$$

$$R_2 = R_1(1+\alpha_1 \Delta t), \quad R_1 = \frac{V}{I(\text{initial})}$$

$$\therefore \quad R_1 = \frac{240}{2.5} = 96\,\Omega$$

$$\therefore \quad 960 = 96\,(1+0.0055\,\Delta t) \qquad \ldots \Delta t = t_2 - t_1$$

$$\therefore \quad \Delta t = 1636.36 = t_2 - 20$$

$$\therefore \quad t_2 = 1656.36\ °\text{C}$$

Q.8 A coil of insulated copper wire has a resistance of 150 Ω at 20 °C. When the coil is connected across a 240 V supply, the current after several hours is 1.25 A. Calculate the temperature of the coil, assuming the temperature co-efficient of resistance of copper at 20°C to be 0.0039 per °C. ☞ **[SPPU : May-15, Marks 6]**

Ans. : $t_1 = 20°\text{C}, \quad R_1 = 150\,\Omega, V = 240\,\text{V}, \quad \alpha_1 = 0.0039/°\text{C}$

$$R_2 = \frac{V}{I_2} = \frac{240}{1.25} = 192\,\Omega \qquad \ldots I_2 = 1.25\ \text{A}$$

$$R_2 = R_1\,[1+\alpha_1(t_2 - t_1)]$$

$$\therefore \quad 192 = 150\,[1+0.0039\,(t_2 - 20)]$$

$$\therefore \quad t_2 - 20 = 71.794 \quad \text{i.e.} \quad t_2 = 91.794°\text{C}$$

Q.9 Find the current flowing at the instant of switching 40 W lamp on 240 V supply. Given that working temperature of filament is 2000 °C and temperature co-efficient of resistance of filament at 15 °C is 0.005 /°C. ☞ **[SPPU : May-16, Marks 6]**

Ans. : $P = 40$ W, $V = 240$ V, $t_2 = 2000$ °C, Assume $t_1 = 25$ °C

$\alpha_3 = 0.005$ / °C at $t_3 = 15$ °C

$$R_2 = \frac{V^2}{P} = \frac{240^2}{40} = 1440\,\Omega$$

Calculate α_1 i.e. α at $t_1 = 25$ °C.

$$(\alpha_1 - \alpha_3) = \alpha_1 \alpha_3 (t_3 - t_1)$$

$$\therefore (\alpha_1 - 0.005) = \alpha_1 \times 0.005 \times (15 - 25)$$

$$\therefore \quad \alpha_1 - 0.005 = -0.05\alpha_1 \quad \text{i.e.} \quad \alpha_1 = 4.762 \times 10^{-3} / °\text{C at } t_1$$

$$R_2 = R_1(1+\alpha_1 \Delta t)$$

$$\text{i.e.} \quad 1440 = R_1\,[1+4.762 \times 10^{-3} \times (2000 - 25)]$$

$$\therefore \quad R_1 = 138.395\ \Omega$$

$$\therefore \quad I = \text{Current at switching time} = \frac{V}{R_1} = 1.734\ \text{A}$$

Q.10 If the temperature coefficient of resistance for copper wire is 0.00393 per degree celsius at 20 °C. Find the temperature coefficient of resistance at [i] 50 °C and [ii] 70 °C. ☞ **[JNTU : May-19, Marks 6]**

Ans. : Given : $\alpha_1 = 0.00393\ /°\text{C}, \ t_1 = 20\ °\text{C}$

To find : α_2 and α_3 at $t_2 = 50$ °C, $t_3 = 70$ °C

$$\text{Find } \alpha_0 \text{ from, } \quad \alpha_t = \frac{\alpha_0}{1+\alpha_0 t} \qquad \ldots (1)$$

$$\therefore \text{ At } t_1, \alpha_1 = \frac{\alpha_0}{1+\alpha_0 t_1} \quad \text{i.e. } 0.00393 = \frac{\alpha_0}{1+20\alpha_0}$$

$$\therefore \quad \alpha_0 = 0.004265\ /°\text{C}$$

i) $t_1 = 50$ °C and using (1),

$$\alpha_2 = \frac{\alpha_0}{1+\alpha_0 t_2} = \frac{0.004265}{1+0.004265 \times 50}$$

$$= 0.003515\ /°\text{C}$$

ii) $t_3 = 70$ °C and using (1),

$$\alpha_3 = \frac{0.004265}{1+0.004265 \times 70}$$

$$= 0.003284\ /°\text{C}$$

Or use the relation,

$$\alpha_2 = \frac{\alpha_1}{1+\alpha_1(t_2 - t_1)}$$

6.3 : Insulation Resistance

Q.11 Define insulation resistance ? Derive an expression for insulation resistance of the cable. State the factors affecting insulation resistance.

☞ **[SPPU : Dec.-04,05,06,07,09,10,11,13,18, May-08,09,11,12,13,15,16, Marks 5]**

Ans. : The resistance which offers opposition to the flow of leakage current is an ideal perfect insulation resistance. It stops the leakage current.

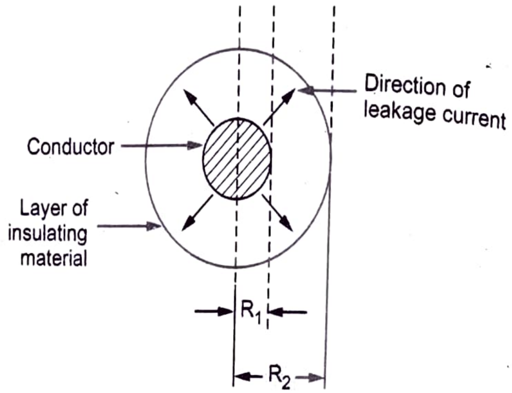


Fig. Q.11.1 Cable and path of leakage current

$$R_i = \frac{V}{I_l} \quad \text{where } R_i = \text{Insulation resistance}$$

- Note that V = Voltage between conductor and earth,
  I_l = Leakage current
- **The value of insulation resistance is always very very high, of the order of megaohms.**
- The Fig. Q.11.1 shows a cable which is insulated with the help of layer of insulating material.
- In such cables, leakage current flows radially from centre towards surface as shown in Fig. Q.11.1. Hence the cross-section of the path of such current is not constant but continuously changes with its length.

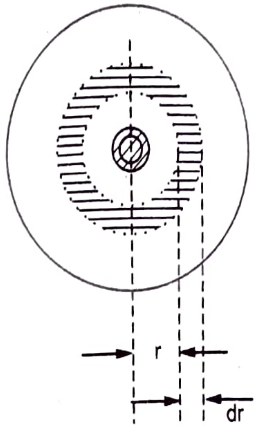


Fig. Q.11.2 Section of length dr

- So to calculate its resistance, it is necessary to consider the section of cylindrical cable of radius r with small thickness dr as shown in the Fig. Q.11.2.
- As leakage current flows redially the length in the direction of current, of this ring is dr only.
- While the total length of cable is say 'l' meters then its corss-sectional area perpendicular to the flow of current is surface area i.e. $2\pi r l$.
- Hence the resistance of this ring can be written as,

$$d R_i = \rho \frac{dr}{2\pi r l} \qquad \ldots \text{ as } R = \frac{\rho l}{a}$$

$l = dr$, $a = 2\pi r l$, ρ = Resistivity

- The total insulation resistance can be obtained by integrating this from inner radius up to outer radius i.e. R_1 to R_2.

$$R_i = \int_{R_1}^{R_2} d R_i = \int_{R_1}^{R_2} \frac{\rho\, dr}{2\pi r l} = \frac{\rho}{2\pi l} \int_{R_1}^{R_2} \frac{dr}{r} = \frac{\rho}{2\pi l}[\text{Log}_e\, r]_{R_1}^{R_2}$$

$$= \frac{\rho}{2\pi l}[\text{Log}_e\, R_2 - \text{Log}_e\, R_1]$$

$$\therefore \quad \boxed{R_i = \frac{\rho}{2\pi l} \text{Log}_e\left(\frac{R_2}{R_1}\right) \ \Omega}$$

The factors on which insulation resistance depends are,

1) Resistivity of the insulating material.

2) Length of the cable.

3) Temperature of the surrounding.

4) Moisture content in the insulating material.

5) Thickness of the insulation.

Important Points to Remember

- As temperature increases, the insulation resistance decreases while conductivity increases.
- The effect can be mathematically expressed interms of an exponential relationship as,

$\therefore \quad R_{it} = R_{i0}\, e^{-\alpha_0 t}$ where R_{it} = Insulation resistance at t °C

R_{i0} = Insulation resistance at 0 °C and α_0 = R.T.C. at 0 °C

- **As moisture content in insulation increases, the insulation resistance decreases.**

Q.12 A single core cable has its conductor diameter as 2 cm and outer diameter as 5 cm. The resistivity of conductor and insulator are $1.73 \times 10^{-8}\ \Omega$-m and $8 \times 10^{12}\ \Omega$-m respectively. Calculate resistance of conductor and insulation for a cable of 100 meter.

☞ [SPPU : Dec.-13, Marks 6]

Ans. : $\rho_c = 1.73 \times 10^{-8}\ \Omega\text{-m},\ \rho_i = 8 \times 10^{12}\ \Omega\text{-m},\ l = 100\ \text{m},$

For conductor, $D_1 = 2$ cm, $R_1 = \frac{D_1}{2} = 1$ cm

$$\therefore \quad a_c = \frac{\pi}{4} D_1^2 = 3.1416 \times 10^{-4}\ \text{m}^2$$

$$\therefore \quad R_c = \frac{\rho_c l}{a_c} = \frac{1.73 \times 10^{-8} \times 100}{3.1416 \times 10^{-4}} = 5.506 \times 10^{-3}\ \Omega$$

For insulation, $R_2 = \frac{D_2}{2} = \frac{5}{2} = 2.5$ cm

$$\therefore \quad R_i = \frac{\rho_i}{2\pi l} \ln\left[\frac{R_2}{R_1}\right] = 1.167 \times 10^{10}\ \Omega$$

6.4 : Conversion of Energy from One Form to Other

Q.13 Explain the following terms related to mechanical quantities : i) Force ii) Work iii) Enrgy iv) Power

Ans. : **i) Force :** It is the push or pull which changes or tends to change the state of rest or uniform motion of body, measured in Newton.

- One newton is the force required to give an acceleration of 1 m/s^2 to a mass of 1 kg.

$$\boxed{F = m \times a}$$

The force is measured in Newtons.

ii) Work : The work is said to be done when force acting on a body causes it to move. If body moves through distance d under the force F then,

$$\boxed{W = F \times d}$$

The work is measured in Joules.

iii) Energy : It is the capacity to do the work. The work is done always at the cost of energy. The unit of energy is also Joules. The two forms of an energy are,

a) **Kinetic energy** which is the energy possessed by a body due to its motion. If body of mass m is moving with velocity v then the kinetic energy is,

$$\boxed{\text{K.E.} = \frac{1}{2} m v^2 \ \ \text{J}}$$

b) **Potential energy** which is the energy possessed by a body due to its position. When a body of mass m is lifted vertically through height of h then the potential energy is,

$$\boxed{P.E. = mgh = wh\ J \qquad \text{where } w = \text{Weight}}$$

iv) Power : The rate of doing work is power measured in J/sec i.e. watts

$$\boxed{P = \frac{\text{Work done}}{\text{Time}}\ \text{J/sec i.e. W}} \quad \text{and} \quad \boxed{1\ W = 1\ J/sec}$$

- Energy expended = Power × Time = Work done

Q.14 Explain following terms with respect to electrical quantities : i) Work ii) Energy iii) Power. State their units. ☞ **[SPPU : May-12, Marks 4]**

Ans. : i) Electrical work : The electrical work is done when there is a transfer of charge. It is measured in Joules.

- One joule of electrical work done is that work done in moving a charge of 1 coulomb through a potential difference of 1 volt.

- So if V is potential difference in volts and Q is charge in coulombs then we can write,

$$\text{Electrical work } W = V \times Q\ J \qquad \text{But } I = \frac{Q}{t}$$

$$\therefore \quad \boxed{W = VIt = I^2 R t = \frac{V^2}{R} t\ \ J \qquad \text{Where } t = \text{Time in seconds}}$$

ii) Electrical power : The rate at which electrical work is done in an electric circuit is called an electrical power.

$$\text{Electrical power } P = \frac{\text{Electrical work}}{\text{Time}} = \frac{W}{t} = \frac{VIt}{t}$$

$$\therefore \quad \boxed{P = VI = I^2R = \frac{V^2}{R}\ \text{J/sec i.e. watts where } R = \text{Resistance in } \Omega}$$

iii) Electrical energy : An electrical energy is the total amount of electrical work done in an electric circuit.

$$\therefore \quad \boxed{\text{Electrical energy } E = \text{Power} \times \text{Time} = VIt \text{ joules}}$$

- **The unit of energy is joules or watt-sec.**
- The energy consumed by an electric circuit is said to be 1 joule or watt-sec when it utilises power of 1 watt for 1 second.

Important Points to Remember

- As watt-sec unit is very small, the electrical energy is measured in bigger units as watt-hour (Wh) and kilo watt-hour (kWh).

$$1\ Wh = 1 \text{ watt} \times 1 \text{ hour} = 1 \text{watt} \times 3600 \text{ sec}$$

$$= 3600 \text{ watt-sec i.e. J}$$

$$\text{and} \quad 1\ kWh = 1000\ Wh = 1 \times 10^3 \times 3600\ J = 3.6 \times 10^6\ J$$

- When a power of 1 kW is utilised for 1 hour the energy consumed is said to be 1 kWh or 1 unit. This unit is called **Board of Trade Unit.** The electricity bills we are getting are charged based on this commercial unit of energy i.e. kWh or unit.

Q.15 A belt driven pulley of 0.4 m in diameter rotates at a speed of 4 revolutions per second. The tension in the tight side of the belt is 420 N and in the slack side 80 N. Calculate : i) The torque on pulley ii) The power developed ☞ **[SPPU : Dec.-17, Marks 7]**

Ans. : $T_1 = 420$ N, $T_2 = 80$ N

∴ Net tension= $T_1 - T_2 = 340$ N

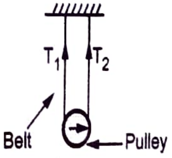


Fig. Q.15.1

i) $T = F \times r$

where F = Net tension

r = Radius of pulley $= \frac{0.4}{2} = 0.2$ m

∴ $T = 340 \times 0.2 = $ **68 Nm**

ii) n = 4 rev per second

$$\therefore \quad \omega = 2\pi n = 8\pi \text{ rad/sec}$$

$$\therefore \quad P = T \times \omega = 68 \times 8 \times \pi = \mathbf{1.71\ kW}$$

Q.16 Find the current drawn by a crane motor when raising a mass of 1000 kg through a height of 15 meters in 10 sec. The supply is 400 V D.C., gear efficiency is 0.6 and motor efficiency is 0.8.
☞ [SPPU : Dec.-12, Marks 6]

Ans. : $m = 1000$ kg, $h = 10$ m, $t = 10$ sec, $V = 400$ V, $\eta_{gear} = 0.6$,

$$\eta_{motor} = 0.8$$

$$P_{out} = mgh = 1000 \times 9.81 \times 10 = 98100 \text{ J}$$

$$\therefore \quad P_{in} = \frac{P_{out}}{\eta_{gear} \times \eta_{motor}} = \frac{98100}{0.6 \times 0.8} = 204375 \text{ J}$$

$$\therefore P_{in} \text{ in watts} = \frac{P_{in}}{\text{time}} = \frac{204375}{10} = 20437.5 \text{ W}$$

But $P_{in} = VI$ i.e. $20437.5 = 400 \times I$

$$\therefore \quad I = \mathbf{51.09375\ A}$$

Q.17 A pump driven by a DC electric motor lifts 1.5 m^3 of water per minute to a height of 40 m. The pump has an efficiency of 90 % and the motor an efficiency of 85 %. Determine i) The power input to the motor, ii) The current taken from a 480 V supply. Assume the mass of one m^3 of water is 1000 kg.
☞ [SPPU : May-14, Marks 6]

Ans. : $1\ m^3 = 1000$ kg, hence $m = 1.5\ m^3 = 1500$ kg, $h = 40$ m,

$$\eta_p = 90\ \%, \ \eta_m = 85\ \%, \ V = 480 \text{ V}$$

$$P_{out} = mgh = 1500 \times 9.81 \times 40 = 588600 \text{ J}$$

$$\therefore \quad P_{in} = \frac{P_{out}}{\eta_m \times \eta_p} = 769411.7647 \text{ J, Time} = 1 \text{ minute}$$

$$\text{i) } P_{in} \text{ in watts} = \frac{P_{in} \text{ in J}}{\text{Time in sec}} = \frac{769411.7647}{60} = \mathbf{12823.529\ W}$$

$$\text{ii) } P_{in} = V \times I \text{ i.e. } I = \frac{12823.529}{480} = \mathbf{26.7157\ A}$$

Q.18 A motor pump set lifts 1200 m^3 of water to a height of 15 meter per hour. If the efficiency of motor is 80 % and that of pump is 75 %, Calculate the monthly bill of set if it is used 4 hrs per day for 30 days at a rate of ₹. 5/unit. ☞ [SPPU : Dec.-14, Marks 6]

Ans. : Mass of 1 m^3 of water is 1000 kg.

$$m = 1200 \times 1000 \text{ kg}, \ h = 15 \text{ m}, \ \eta_m = 80\ \%, \ \eta_p = 75\ \%$$

$$\therefore \quad P_{out} = mgh = 1200 \times 1000 \times 9.81 \times 15 = 176.58 \times 10^6 \text{ J}$$

$$\therefore \quad P_{out} = \frac{P_{out} \text{ in J}}{\text{time}} = \frac{176.58 \times 10^6}{3600} = 49.05 \text{ kW}$$

... t = 1 hour = 3600 sec

$$\therefore \quad P_{in} = \frac{P_{out}}{\eta_m \times \eta_p} = \frac{49.05}{0.8 \times 0.75} = 81.75 \text{ kW}$$

Per day 4 hours i.e. daily consumption = 4 × 81.75 = 327 kWh

Monthly consumption = 327 × 30 = 9810 kWh = 9810 units

∴ Monthly bill = 9810 × (5 ₹./unit) = **₹. 49050/-**

Q.19 A water pump lifts 50 m^3 of water per hour to a height of 20 m. The overall efficiency of water pump set is 0.60. Find monthly bill, when the pump is used 4 hours a day for a month of 30 days, at the rate of ₹ 5/kWh. ☞ [SPPU : Dec.-15, Marks 6]

Ans. : $1\ m^3 = 1000$ kg,

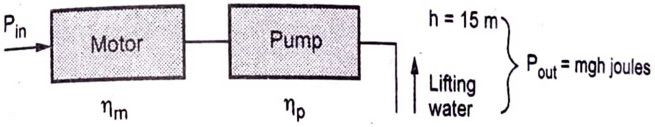


Fig. Q.19.1

$$m = 50 \times 10^3 \text{ kg}, \ h = 20 \text{ m}, \ \eta = 0.6, \ t = 1 \text{ hour} = 3600 \text{ sec}$$

$$\therefore \quad P_{out} = mgh = 50 \times 10^3 \times 9.81 \times 20 = 9.81 \times 10^6 \text{ J}$$

$$\therefore P_{out} \text{ in W} = \frac{9.81 \times 10^6}{3600} = 2725 \text{ W}$$

$$\therefore \quad P_{in} = \frac{P_{out}}{\eta} = \frac{2725}{0.6} = 4541.67 \text{ W} = 4.542 \text{ kW}$$

$$\text{Daily consumption} = P_{in} \times \text{hours/day} = 4.542 \times 4$$

$$= 18.167 \text{ kWh}$$

$$\therefore \text{Monthly consumption} = 18.167 \times 30 = 545 \text{ kWh}$$

$$\therefore \quad \text{Monthly bill} = 545 \times (₹\ 5/\text{kWh}) = \mathbf{₹\ 2725/-}$$

Q.20 An electric kettle is required to raise the temperature of 2 litres of water from 20 °C to 100 °C in 15 mins. Calculate the resistance of the heating element if the kettle is to be used on 200 V supply. Assume efficiency of the kettle to be 80 %. Assume specific heat of water 4180 J/kg-K. ☞ **[SPPU : Dec.-16, Marks 6]**

Ans. : $m = 2$ litres $= 2$ kg, $C = 4180$ J/kg °K, $t_1 = 20$ °C, $t_2 = 100$ °C,

$t = 15$ min $= 900$ sec., $\eta = 80$ %, $V = 200$ V

$$\therefore \quad E_{out} = mC\Delta t = 4180 \times 2 \times (100 - 20) = 668.8 \times 10^3 \text{ J}$$

$$\therefore \quad E_{in} = \frac{E_{out}}{\eta} = \frac{668.8 \times 10^3}{0.8} = 836 \times 10^3 \text{ J}$$

$$\therefore \quad P_{in} = \frac{E_{in} \text{ in J}}{\text{time in sec}} = \frac{836 \times 10^3}{900} = 928.888 \text{ W}$$

$$\text{But} \quad P_{in} = VI \quad \text{i.e.} \quad I = \frac{P_{in}}{V} = \frac{928.888}{200} = \mathbf{4.644 \text{ A}}$$

$$\therefore \quad R = \frac{V}{I} = \frac{200}{4.644} = \mathbf{43.0622\ \Omega}$$

Q.21 An electric motor runs at 600 rpm and produces a torque of 210 N-m. The motor efficiency is 88 %. Find motor input power and current drawn when motor is fed at 400 V DC supply. ☞ **[SPPU : May-17, Marks 6]**

Ans. : $N = 600$ r.p.m., $T = 210$ Nm, $\eta = 88$ %, $V = 400$ V

$$P_{out} = T \times \omega = T \times \frac{2\pi N}{60} = \frac{210 \times 2\pi \times 600}{60} = 13.195 \text{ kW}$$

$$\therefore \quad P_{in} = \frac{P_{out}}{\eta} = \frac{13.195}{0.88} = \mathbf{15 \text{ kW}}$$

$$P_{in} = VI \quad \text{i.e.} \quad I = \frac{15 \times 10^3}{400} = \mathbf{37.5}$$

Q.22 In a hydro electric generating station, the head of water is 425 m. If 1250 liters of water are required to generate 1 kWh of electric energy, find the overall efficiency. Assume 1 liter = 1 kg. ☞ **[SPPU : May-18, Marks 7]**

Ans. : $m = 1250$ kg, $h = 425$ m

$$\text{Energy produced} = mgh = 1250 \times 9.81 \times 425 = 5.212 \times 10^6 \text{ J}$$

$$\text{Energy produced in 1 hour} = \frac{mgh}{3600} = 1447.6563 \text{ Wh}$$

$$= 1.4476 \text{ kWh}$$

$$\text{Actual generation} = 1 \text{ kWh}$$

$$\therefore \quad \%\eta = \frac{\text{Generated}}{\text{Produced}} \times 100 = \frac{1}{1.4476} \times 100 = \mathbf{69.077\ \%}$$

Section B : Batteries

6.5 : Introduction to Batteries

Q.23 Define cell and battery.

Ans. : Cell : A device which works on the principle of conversion of chemical energy into an eletrical energy and is used as a source of e.m.f. is called a **cell.**

Battery : The device formed by combination (series, parallel or series - parallel) of various cells to obtain desired voltage level is called **battery.**

6.6 : Classification of Cells

Q.24 Explain primary and secondary cells giving examples.

Ans. : • **Cells are classified as follows**

1. **Primary cells :** The cells in which the chemical action is irreversible and which can not be recharged are called **primary cells.**

   Examples : Zinc-carbon dry cell, zinc-chloride cell, alkaline cells, mercury cells.

- The primary cells can produce only limited amount of energy. In such cells mostly non-electrolytes are used.

2. **Secondary cells :** The cells in which the chemical action is reversible and they can be recharged are called **secondary cells.**

   Examples : Lead-acid cell, nickel-cadmium cell etc.

- In secondary cells, chemical energy is stored in the form of chemical energy and the secondary cells thus also called **storage** cells or **accumulators.**
- When the cell discharges, it can be charged to regain its original charged state hence secondary cells are also called **rechargeable** cells.
- The secondary cells can produce large amount of energy.

Q.25 Give comparison between primary cell and secondary cells. State any six points.

Sr. No.	Primary cells	Secondary cells
1.	Electrical energy is directly obtained from chemical energy.	Electrical energy is present in the cell in the form of chemical energy and then converted to electrical energy.
2.	The chemical actions are irreversible.	The chemical actions are reversible.
3.	Cell is completely replaced when it goes down.	The cell is recharged back when it goes down.
4.	Polarisation is present.	Polarisation is absent.
5.	Low efficiency.	Efficiency is high
6.	Capacity is low.	Higher capacity.
7.	Less cost.	High initial cost.
8.	No maintenance required.	Frequent charging and other maintenance is required.
9.	Examples are dry cell, mercury cell, zinc-chloride cell.	Examples are Nickel-iron, Lead acid and Nickel-cadmium.

6.7 : Lead Acid Battery

Q.26 With a neat diagram describe the construction of a lead acid cell.

OR List various parts of lead acid battery and explain them in brief.

Ans. :

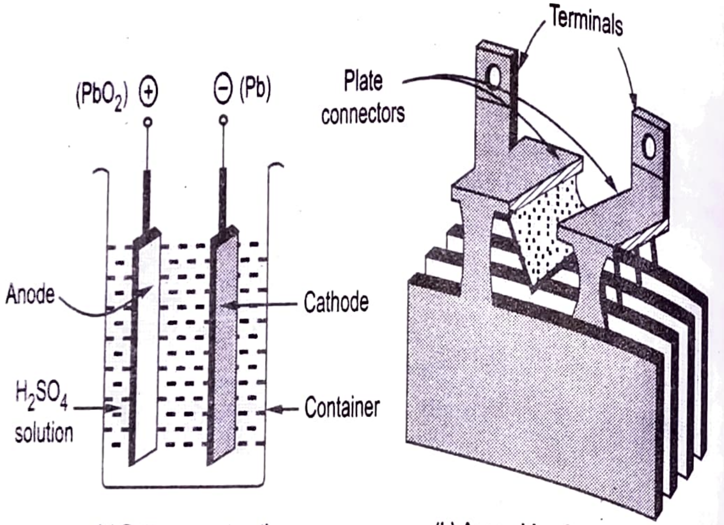
- The various parts of lead acid battery are,

1. **Positive plate or anode :** It is **lead peroxide** (PbO_2) plate of chocolate, dark brown colour.
2. **Negative plate or cathode :** It is made up of **pure lead** (Pb) which is grey in colour.
3. **Electrolyte :** For the necessary chemical action aqueous solution of **sulphuric acid** (H_2SO_4) is used as an electrolyte.
4. **Seperators :** The positive and negative plates are arranged in groups and are placed alternately. The seperators are used to prevent them from coming in contact with each other short circuiting the cell.
5. **Container :** The entire assembly of plates along with the solution is placed in the plastic or ceramic container.
6. **Bottom blocks :** To prevent the short circuiting of cell due to the active material fallen from the plates, the space known as bottom blocks is provided at the bottom of the container.
7. **Plate connector :** The number of negative and positive plates are assembled alternately. To connect the positive plates together separate connectors are used which are called plate connectors.

The upward connections of the plate connectors are nothing but the terminals of the cell.

8. **Vent-plug** : These are made up of rubber and screwed to the cover of the cell. Its function is to allow the escape of gases and prevent escape of electroyte.

The Fig. Q.26.1 shows the construction of lead acid battery.



(a) Battery construction (b) Assembly of – ve and + ve plates

Fig. Q.26.1 Construction of lead acid battery

- The various plates are welded to the plate connectors. The plates are immersed in H_2SO_4 solution. Each plate is a grid or frame work. Except some special assemblies, wide space between the plates is provided. In an alternate assembly of plates, the **negative plate is one more in number than positive.** So all the positive plates can work on both the sides.

Q.27 Name the active materials used in lead acid battery.

Definition : The materials which undergo chemical reactions and physical changes during charging and discharging are called **active materials.**

- The active materials used in lead acid battery are as follows

Lead peroxide (PbO_2) - Positive plate or anode
Pure lead (Pb) - Negative plate or cathode
Dilute or aqueous sulphuric acid (H_2SO_4) - Electrolyte

Q.28 Write about chemical actions and physical changes during the charging and discharging of lead acid batteries.

Ans. :

- The chemical action in the lead acid battery can be divided into three processes namely; 1) First charging, 2) Discharging, and 3) Recharging.

1) First charging :

Chemical Reactions

- For the first time when current is passed through electrolyte, the H_2O in the electrolyte is electrolysed as,

$$H_2O \rightarrow 2H^+ + O^-$$

- As the hydrogen ions are positively charged, they gets attracted towards cathode. The hydrogen ions do not combine with lead.
- The oxygen ions are negative charged, and they gets attracted towards anode which is positive electrode. The oxygen ions combine with lead to form lead peroxide (PbO_2)
- So there exists potential difference between + ve anode and – ve cathode which can drive the external circuit.
- The electrical energy from chemical reaction is drawn out of battery to the external circuit by the process known as **discharging.**

Physical Changes

- When hydrogen ions are attracted towards cathode, they cannot combine with lead. Hence cathode retains its original state and color. Thus **cathode remains as spongy lead electrode.**

- When oxygen ions are attracted towards anode, they combine with the lead (Pb) to form lead peroxide. Thus **anode becomes dark brown in color.**

2) Discharging :

- When the external supply is removed and a resistance is connected between anode and cathode, current flows through it which is called discharging.
- The direction of current is opposite to the direction of current at the time of first charging.

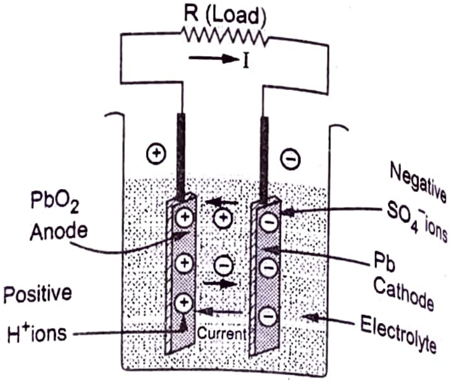


Fig. Q.28.1 Discharging

Chemical Reactions

- During discharging, H^+ ions move towards anode and SO_4^{--} ions move towards cathode because H_2SO_4 decomposes as follows.

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{--}$$

- **At anode,** the H^+ ions react with PbO_2 and H_2SO_4 resulting in lead sulphate ($PbSO_4$) as,

$$PbO_2 + H_2SO_4 + 2H \rightarrow PbSO_4 + 2H_2O$$

- **At cathode,** each SO_4^{--} ion becomes free SO_4 and reacts with metallic lead to result in lead sulphate ($PbSO_4$) given as,

$$Pb + SO_4 \rightarrow PbSO_4$$

Physical Changes

- Both the electrodes are with $PbSO_4$ which is whitish in colour.

- As water (H_2O) is formed, the specific gravity of electrolyte decreases.

3) Recharging :

- The cell provides discharge current for limited time.
- It is necessary to recharge cell at regular interval of time.
- So using an external supply again e.m.f. is injected through the terminals of cell.

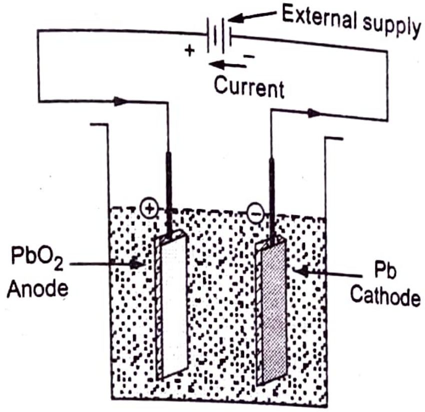


Fig. Q.28.2 Recharging the lead acid battery

- Due to this recharging current flows and following reactions take place.

Chemical Reaction

- **At cathode,** H^+ ions move forwards cathode and react with $PbSO_4$ forming H_2SO_4 and lead at electrode given as,

$$PbSO_4 + 2H \rightarrow Pb + H_2SO_4$$

- **At anode,** SO_4 ions react with $PbSO_4$ along with water to form again lead peroxide at electrode and H_2SO_4 given by,

$$PbSO_4 + SO_4 + 2H_2O \rightarrow PbO_2 + 2H_2SO_4$$

Physical Changes

- The anode becomes PbO_2 and regains its original colour as dark brown.
- The cathode becomes Pb and regains its original colour as gray.

Due to the absorption of H_2O (water), the specific gravity of electrolyte increases. **Note that more is the specific gravity of electrolyte (i.e. H_2SO_4) better is the charging.**

Q.29 List various features of lead acid battery.

Ans. :

1. The capacity is about 100 to 300 ampere-hours.
2. The voltage is 2.2 V for fully charged condition.
3. The cost is low.
4. The internal resistance is very low.
5. The current ratings are high.
6. The ampere-hour efficiency is about 90 to 95 % with 10 hour rate.

Q.30 State any three conditions of fully charged lead acid battery.

Ans. : For identifying whether the battery is fully charged or not, following conditions must be observed,

1. The specific gravity of H_2SO_4 must be 1.25 to 1.28.
2. The voltage stops to rise and its value is about 2.2 to 2.5 V.
3. Violent gasing starts as battery is fully charged.
4. The colour of positive plate becomes dark brown while the colour of negative plate becomes slate grey.

6.8 : Lithium Ion Battery

Q.31 Explain the construction of lithium ion battery.

Ans. : • A lithium ion battery is made up of an anode, cathode, separator, electrolyte and two current collectors (positive and negative).

- Lithium ion battery uses **carbon** electrode as its **anode** with a current collector of thin copper foil.
- It uses **cathode** which is made up from Lithium liberating compounds such as,

1) Lithium Cobalt Oxide ($LiCoO_2$)

2) Lithium Manganese Oxide ($LiMn_2O_4$)

3) Lithium Nickel Oxide ($LiNiO_2$)

- Out of the above materials, **Lithium cobalt oxide** is commonly used for **cathode** with the current collector made up of thin aluminium foil.
- A **separator** is a fine porous **polymer film.**
- An **electrolyte** is solution based on a **lithium salt** in an organic solvent. The type of conductivity of an electrolyte is ionic rather than electronic.
- Both the electrodes are made up of materials which can **'intercalate'** or **'absorb'** the lithium ions. When the charged ions of an element can be absorbed and held inside the structure of a host material without disturbing it then it is called **intercalation.** The lithium ions are tied to an electron within the structure of the anode.
- The Fig. Q.31.1 shows schematic representation of Lithium ion battery.

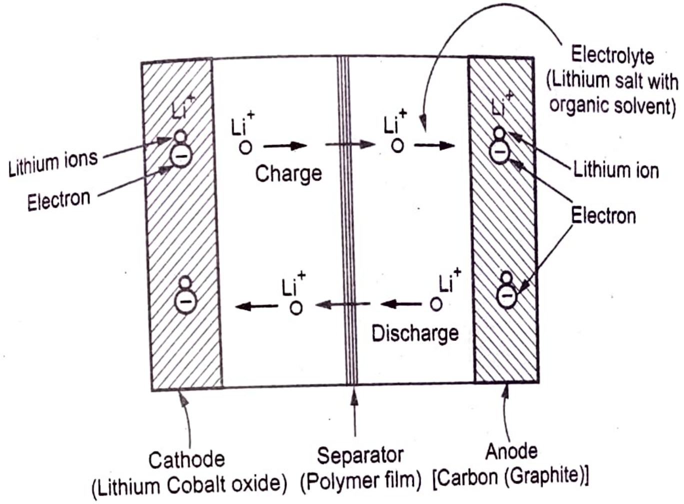
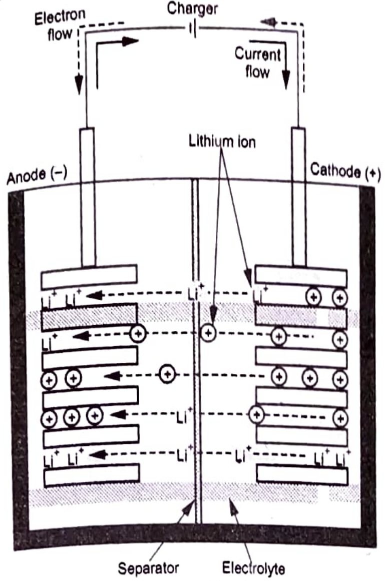

Electrolyte (Lithium salt with organic solvent)
Lithium ions
Electron
Li^+
Charge
Li^+
Lithium ion
Electron
Li^+
Li^+
Discharge
Cathode (Lithium Cobalt oxide)
Separator (Polymer film)
Anode [Carbon (Graphite)]

Fig. Q.31.1 Schematic representation of Lithium Ion battery

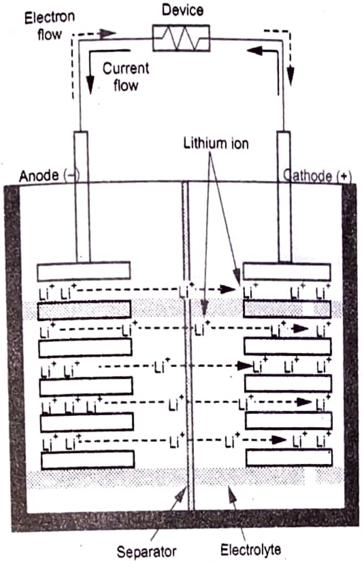
Q.32 Explain the working of lithium ion battery.

Ans. : • A lithium ion battery starts its life in a state of full discharge. Thus all its lithium ions are inserted in cathode.

- For charging, the battery is connected to an external power supply. Due to this, oxidation reaction occurs at the cathode and it looses electrons which are negatively charged.
- To maintain the charge balance in the cathode, equal number of lithium ions are dissolved in electrolyte solution. The lithium ions are positively charged.
- The lithium ions travel through the electrolyte and reach to anode. The lithium ions are intercalated within carbon anode.
- The separator used does not allow electrons to flow through an electrolyte. The electrons travel through the external wire and reach to anode from cathode. At anode, the electrons get tied with lithium ions.
- At the time of discharging, the opposite reaction occurs. While discharging, the anode releases lithium ions and electrons.
- The lithium ions get dissolved into electrolyte and travel towards the cathode. While due to separator, the electrons flow from the external circuit.
- Due to the flow of electrons from the external circuit, the current is established and the device connected to battery is operated.
- The positively charged lithium ions balance the number of negatively charged electrons.
- When the cathode is full of lithium ions the discharging stops and battery needs to be recharged again.
- The charging and discharging is shown in the Fig. Q.32.1 (a) and (b).



(a) During charging



(b) During discharging

Fig. Q.32.1 Working of lithium ion battery

Q.33 State the advantages and applications of lithium ion battery.

Ans. : Advantages

1) The energy density of lithium ion battery is very high. Being light and small, large lithium can be stored in both the electrodes providing large number of lithium ions.
2) The cell voltage is high which is about 3.6 V. Thus less number of cells are required if high voltage is required.
3) The battery is light in weight and compact in size.
4) It handles many charging - discharging cycles.
5) It holds its charge for longer period. It loses only 5 % of its charge per month.
6) It has no memory effect i.e. it is not required to discharge it completely before charging.
7) It has built in protection to prevent overheating.
8) It requires no maintenance to ensure the performance.
9) The several types of lithium ion batteries are available with variety of shapes and sizes.
10) It is rechargeable battery.

Applications

1) Used in cameras and calculators.
2) Used in mobile phones, portable radios and laptops.
3) Used in aerospace applications.
4) Used in cardiac pacemakers and other implantable devices.
5) Used in electric vehicles and mine detectors.
6) Used in toys and rechargeable flash lights.

6.9 : Characteristics of Battery

Q.34. Explain the important characteristics for batteries.

Ans. : The variopus important characteristics for batteries are

1. **Nominal voltage :** It is indicated on a battery depending on the amount of cells connected in series. It is the open circuit voltage of a battery.

2. **Battery capacity or battery life :** It is specified in ampere-hours (Ah).

- It indicates the amount of electricity which a battery can supply at the specified discharge rate till its voltage falls to a specified value.
- Mathematically product of discharge current (I_D) in amperes and the time for discharge (T_D) in hours till voltage falls to a specified value is the capacity of a battery.

$$\boxed{\text{Battery capacity} = I_D \times T_D \text{ (Ah)}}$$

∴

3. **Specific gravity of electrolyte :** More the specific gravity of electrolyte, more is the battery capacity. It decides internal resistance of a battery.

4. **Specific energy :** The battery capacity expressed in watt-hour per kg weight is called specific energy. It is also called **gravimetric energy density** of a battery.

5. **Electrical characteristics :** These characteristics include, the charging and discharging curves for a battery. It is the graph of terminal voltage against charging or discharging time in hours at normal rate. The Fig. Q.34.1 shows such curves for a typical battery. From the given charging and discharging curves, the time of discharge for a specified voltage level can be obtained.

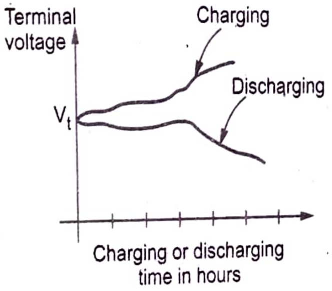


Fig. Q.34.1

6. **Battery efficiency :** It is defined as the ratio of the output during discharging

to the input required during charging, to regain the original state of the battery.

- It is commonly called **ampere-hour efficiency** or **quantity efficiency** and denoted as η_{Ah}.

$$\eta_{Ah} = \frac{\text{Amp-hours on discharge}}{\text{Amp-hours on charge}}$$

$$\therefore \quad \boxed{\%\eta_{Ah} = \left[\frac{\text{Current} \times \text{Time on discharge}}{\text{Current} \times \text{Time on charge}}\right] \times 100}$$

- For lead acid battery, it is about 80 % to 90 %.

6.10 : Concept of Depth of Discharging

Q.35 Explain the significance of depth of discharging.

Ans. : • The depth of discharge is a key factor for any battery. It is denoted as DoD.

- It indicates the degree to which the battery can be discharged to certain minimum voltage from its full state of charge.
- Though the battery capacity is mentioned by the manufacturer, it is not possible to use its entire capacity. The depth of discharge gives the indication that up to which level of discharge, the battery capacity can be used safely.
- Depth of Discharge (DoD) is defined as the capacity in Ampere Hours (Ah) that is discharged from a fully charged battery, divided by battery nominal capacity. DoD is normally represented in percent (%).
- For example if a 200 Ah battery is discharged at 90 A for 30 minutes then its depth of discharge is,

$$\boxed{\begin{aligned} \text{DoD} &= 30/60 \times 90 \times 1/200 \times 100 \\ &= 22.5\ \% \end{aligned}}$$

- When the battery is discharged to its full energy capacity then its DoD is 100 %.
- The depth of discharge is important because the life span of many batteries such a lead acid battery and lithium ion battery depends heavily upon the number of charge and discharge cycles. If the depth of discharge is high then the life span of the battery gets shortened. For example, a battery may have 5,000 cycles at 20 % DoD but only 1500 cycles at 80 % DoD.
- Lithium ion batteries can typically be discharged up to 80 % before reaching a potentially harmful state of deep discharge. They have a battery management system to prevent deep discharge.
- Most battery manufacturers indicate in the specification sheet the maximum recommended DoD for peak performance of the battery. If the manufacturer of a 20 kWh battery recommends a maximum DoD of 60 %, it means that you should avoid discharging more than 12 kWh without recharging.

6.11 : Maintenance of Batteries

Q.36 List the safety precautions to be taken in battery maintenance.

Ans. : • The following care must be taken for the safety purposes **in battery maintenance,**

1. The person doing the maintenance must be authorized person.
2. The person doing the maintenance must have protecting equipments such as goggles, chemical resistance gloves, protective apron and protective overshoes.
3. Before entering the battery room ensure that the ventilation system is operable and in service.
4. Verify that the Unintterupted Power Supply (UPS) is off and power cord is disconnected from the source.

5. Remove watch, ring or other metal objects while doing the maintenance.
6. Use the maintenance tools with insulated handles.
7. Do not put tools or metal parts on the top of batteries.
8. Ensure that sufficient acid neutralizer like baking soda is available.
9. Make sure that sufficient water facilities are available nearby.
10. Prohibit smoking, open flames and any possible arc producing activities near battery.
11. Verify circuit polarities before making the connections.
12. Use proper lifting arrangements for the moving batteries.
13. Check battery system grounding. Battery system grounding is not recommended but the battery rack grounding is recommended.

6.12 : Grouping of Batteries

Important Points to remember

- The batteries can be grouped as,

  i) Series ii) Parallel iii) Series - parallel.

Q.37 Explain the series, parallel and series - parallel grouping of batteries.

Ans. : i) Series grouping

- The Fig. Q.37.1 shows the series grouping of batteries. There are n batteries connected in series.

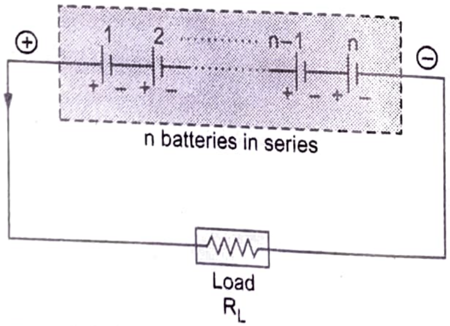


Fig. Q.37.1 Series grouping of batteries

Let E = E.M.F. of each battery

r = Internal resistance of each battery

V = Total voltage available

∴ = n × E volts

R_T = Total circuit resistance = Load + Cells = $R_L + n \times r$

$$\therefore \quad I = \frac{\text{Total voltage}}{\text{Total resistance}} = \frac{V}{R_T} = \frac{nE}{R_L + nr} \text{ A}$$

- In series circuit, current remains same. So this method does not improve current capacity. The current capacity is same as that of each battery connected in series. But voltage can be increased by increasing number of batteries 'n'.

ii) Parallel : In this method, positive terminals of batteries are connected together and negative terminals are connected together as shown in the Fig. Q.37.2.

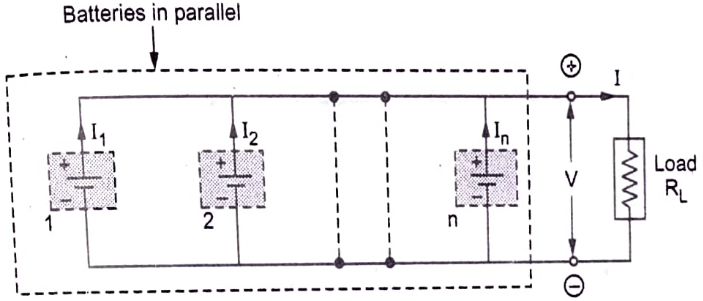


Fig. Q.37.2 Parallel grouping of batteries

- The terminal e.m.f. of each battery must be same as E.

∴ V = Battery voltage = E = e.m.f. of each battery

r = Internal resistance of each battery

I_n = Current through n^{th} branch

∴ I = Total current = $I_1 + I_2 + I_3 + \ldots + I_n$

- It can be seen that in parallel grouping, the voltage remains same but by increasing number of batteries the current capacity can be increased.
- **In series grouping current rating of each battery must be same while in parallel grouping voltage rating of each battery must be same.**

iii) Series-parallel grouping :

- Practically the various groups can be connected in parallel where each group is a series combination of batteries as shown in the Fig. Q.37.3.

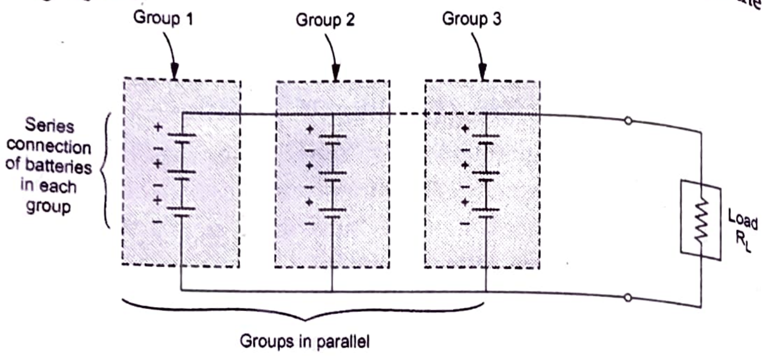
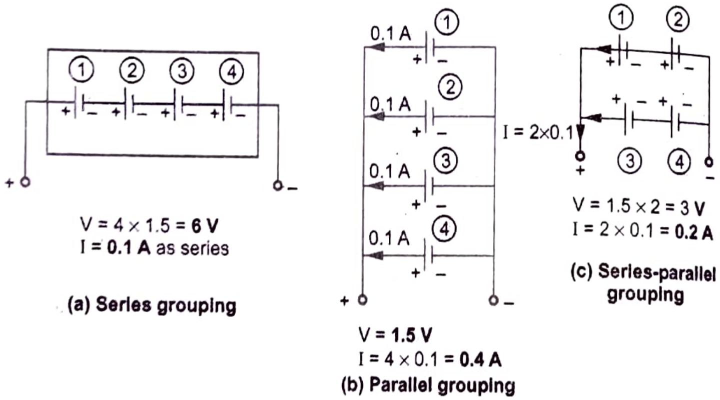


Fig. Q.37.3 Series-parallel grouping

- This is used to satisfy both voltage and current requirement of the load.

Q.38 Show how four batteries, each rated 1.5 V, 0.1 A, can be connected as batteries in three different ways to obtain different voltage and current ratings. State the voltage and current ratings of each type. ☞ **[SPPU : May-05, Marks 6]**

Ans. : The three ways in which batteries can be connected are shown in Fig. Q.38.1.



(a) Series grouping

(b) Parallel grouping

(c) Series-parallel grouping

Fig. Q.38.1

END...

QUESTION BANK FOR END SEM EXAM

Unit - III Single Phase A.C. Circuits

Q.1 *Prove that the voltage and current in purely resistive circuit are in phase.* **(Refer Q.1 of Chapter 3)** **[4]**

Q.2 *Derive an expression for the instantaneous power in a purely resistive circuit excited by sinusoidal voltage.* **(Refer Q.2 of Chapter 3)** **[4]**

Q.3 *Derive the expressions for current and power for purely inductive circuit when the voltage applied to it is $v(t) = V_m \sin \omega t$. Draw the corresponding phasor diagram.* **(Refer Q.5 of Chapter 3)** **[6]**

Q.4 *Derive the expressions for current and power for purely capacitive circuit when the voltage applied to it is $v(t) = V_m \sin \omega t$. Draw the corresponding phasor diagram.* **(Refer Q.8 of Chapter 3)** **[6]**

Q.5 *Derive the expression for the current for R-L series circuit when supplied by a voltage $v(t) = V_m \sin \omega t$. Draw the phasor diagram.* **(Refer Q.11 of Chapter 3)** **[6]**

Q.6 *For a single-phase a.c circuit, the applied voltage is $v = V_m \sin \omega t$ and current drawn is $i = I_m \sin(\omega t - \phi)$. Derive expression for average power. Draw waveforms of voltage, current and instantaneous power over one cycle of voltage.* **(Refer Q.12 of Chapter 3)** **[6]**

Q.7 *Draw power triangle and define active power, reactive power and apparent power.* **(Refer Q.14 of Chapter 3)** **[4]**

Q.8 *Define impedance and power factor of an a.c. circuit.*
(Refer Q.13 and Q.15 of Chapter 3) **[4]**

Q.9 *Derive an expression for current drawn and power consumed by a circuit consisting of 'R' and 'C' connected in series across* $v = V_m \sin \omega t$ *supply.* **(Refer Q.19 of Chapter 3)** **[6]**

Q.10 *Sketch and explain the phasor diagram of RLC series circuit for i)* $X_C > X_L$ *ii)* $X_C < X_L$ *iii)* $X_C = X_L$.
(Refer Q.23 of Chapter 3) **[6]**

Q.11 *What is admittance ? Which are its two components ? State their units. How the admittance is expressed in rectangular and polar form ?* **(Refer Q.26 of Chapter 3)** **[5]**

Q.12 *Draw the admittance triangle and explain.*
(Refer Q.27 of Chapter 3) **[3]**

Q.13 *What is resonance in series circuit ? Derive the expression for the series resonating frequency.*
(Refer Q.30 and Q.32 of Chapter 3) **[6]**

Q.14 *State the charactersitics of series resonance.*
(Refer Q.31 of Chapter 3) **[4]**

Unit - IV Polyphase A.C. Circuits and Single Phase Transformers

Q.1 *State the various advantages of three phase system over single phase system.* **(Refer Q.1 of Chapter 4)** **[6]**

Q.2 *Define the following :*
i) Phase sequence ii) Symmetrical three phase system
(Refer Q.2 and Q.3 of Chapter 4) **[4]**

Q.3 *Define balanced and unbalanced load.*
(Refer Q.5 of Chapter 4) **[3]**

Q.4 *Derive the relation between line and phase values of currents and voltages for balanced three phase star connected load connected across three phase a.c. supply. Derive also power consumed by the load.* **(Refer Q.6 of Chapter 4)** **[6]**

Q.5 *Draw a complete phasor diagram for three phase star connected inductive load connected across three phase a.c. supply.*
(Refer Q.7 of Chapter 4) **[6]**

Q.6 *Derive the relation between line and phase values of currents and voltages for balanced three phase star connected load connected across three phase a.c. supply. Derive also power consumed by the load.* **(Refer Q.8 of Chapter 4)** **[6]**

Q.7 *Draw a complete phasor diagram for three phase delta connected inductive load connected across three phase a.c. supply.*
(Refer Q.9 of Chapter 4) **[6]**

Q.8 *State the equations for real power, apparent power and reactive power for three phase balanced load. Draw the power triangle.* **(Refer Q.10 of Chapter 4)** **[4]**

Q.9 *Explain the working principle of transformer.*
(Refer Q.18 of Chapter 4) **[4]**

Q.10 *Draw the neat sketchs to show the constructional of core and shell type transformers.* **(Refer Q.19 of Chapter 4)** **[4]**

Q.11 *Compare core type and shell type transformers.*
(Refer Q.20 of Chapter 4) [6]

Q.12 *With neat sketches, explain the various types of lamination used for the construction of core of single phase transformer.*
(Refer Q.21 of Chapter 4) [6]

Q.13 *Derive the e.m.f. equation of a transformer.*
(Refer Q.22 of Chapter 4) [6]

Q.14 *Define regulation of transformer. State its expression. How it depends on the load power factor ? Sketch the regulation characteristics.* **(Refer Q.29 of Chapter 4)** [6]

Q.15 *Explain the various losses in a transformer. In which part these losses occur ? How to minimize them ? On which factors they depend ?* **(Refer Q.30 of Chapter 4)** [6]

Q.16 *Derive the condition for the maximum efficiency for a transformer.* **(Refer Q.32 of Chapter 4)** [6]

Q.17 *With the help of neat circuit diagram, describe the method of testing a single phase transformer by direct laoding. Explain how the efficiency and regulation are calculated from the test results.*
(Refer Q.38 of Chapter 4) [6]

Q.18 *Explain the working principle of autotransformer.*
(Refer Q.40 of Chapter 4) [4]

Q.19 *State the advantages, disadvantages and applications of autotransformer.* **(Refer Q.41 of Chapter 4)** [6]

Unit - V D.C. Circuits

Q.1 *Classify the electrical networks.* **(Refer Q.1 of Chapter 5)** [6]

Q.2 *Explain ideal and practical voltage sources.*
(Refer Q.3 of Chapter 5) [4]

Q.3 *Explain ideal and practical current sources.*
(Refer Q.4 of Chapter 5) [4]

Q.4 *State and explain Kirchhoff's laws.* **(Refer Q.6 of Chapter 5)** [6]

Q.5 *Define star and delta connection of resistances.*
(Refer Q.8 of Chapter 5) [4]

Q.6 *Derive equations to convert delta connected resistances to equivalent star connected resistances.*
(Refer Q.9 of Chapter 5) [6]

Q.7 *Derive an equations to convert star connected resistances to equivalent delta connected resistances.*
(Refer Q.10 of Chapter 5) [6]

Q.8 *State and explain Superposition theorem.*
(Refer Q.19 of Chapter 5) [6]

Q.9 *State and explain Thevenin's theorem.*
(Refer Q.23 of Chapter 5) 6

Q.10 *Explain the steps to apply Thevenin's theorem to obtain Thevenin's equivalent circuit.* **(Refer Q.24 of Chapter 5)** 6

Unit - VI Work, Power, Energy and Batteries

Q.1 *Discuss the effect of temperature on the resistance of various materials with the help of a graph.* **(Refer Q.1 of Chapter 6)** **[6]**

Q.2 *What is semiconductor ? Give two examples. Explain the effect of temperature on semiconductors.* **(Refer Q.2 of Chapter 6)** **[4]**

Q.3 *Define temperature coefficient of resistance and state its unit. State the factors on which it depends.*
(Refer Q.3 of Chapter 6) **[4]**

Q.4 *With usual notations, obtain the expression* $\alpha_2 = \dfrac{\alpha_1}{1+\alpha_1(t_2-t_1)}$

and hence obtain $\alpha_t = \dfrac{\alpha_0}{1+\alpha_0 \cdot t}$ *and then* $\alpha_0 = \dfrac{\alpha_1}{1-\alpha_1 \cdot t}$.

(Refer Q.5 of Chapter 6) **[6]**

Q.5 *Define insulation resistance ? Derive an expression for insulation resistance of the cable. State the factors affecting insulation resistance.* **(Refer Q.11 of Chapter 6)** **[6]**

Q.6 *Explain following terms with respect to electrical quantities :*
i) Work ii) Energy iii) Power. State their units.
(Refer Q.14 of Chapter 6) **[6]**

Q.7 *Give comparison between primary cell and secondary cells. State any six points.* **(Refer Q.25 of Chapter 6)** **[4]**

Q.8 *With a neat diagram describe the construction of a lead acid cell.*
(Refer Q.26 of Chapter 6) **[6]**

Q.9 *Write about chemical actions and physical changes during the charging and discharging of lead acid batteries.*
(Refer Q.28 of Chapter 6) **[6]**

Q.10 *State any three conditions of fully charged lead acid battery.*
(Refer Q.30 of Chapter 6) **[3]**

Q.11 *Explain the construction of lithium ion battery.*
(Refer Q.31 of Chapter 6) **[6]**

Q.12 *Explain the working of lithium ion battery.*
(Refer Q.32 of Chapter 6) **[6]**

Q.13 *State the advantages and applications of lithium ion battery.*
(Refer Q.33 of Chapter 6) **[4]**

Q.14 *Explain the important characteristics for batteries.*
(Refer Q.34 of Chapter 6) **[6]**

Q.15 *Explain the significance of depth of discharging.*
(Refer Q.35 of Chapter 6) **[4]**

Q.16 *List the safety precautions to be taken in battery maintenance.*
(Refer Q.36 of Chapter 6) **[6]**

Q.17 *Explain the series, parallel and series - parallel grouping of batteries.* **(Refer Q.37 of Chapter 6)** **[6]**

END...✍

SOLVED SAMPLE QUESTION PAPER - 1 [END SEM]

(AS PER 2019 PATTERN)

Time : $2\frac{1}{2}$ Hours] **[Max. Marks : 70**

Instructions to the candidates :

(1) Answer Q.1 or Q.2, Q.3 or Q.4, Q.5 or Q.6, Q.7 or Q.8

(2) Neat diagrams must be drawn wherever necessary.

(3) Figure to the right indicate full marks

(4) Make suitable assumptions if necessary

Q.1 a) *Define active power, reactive power and apparent power. Draw the power triangle for R-L series circuit.* **(Refer Q.14 of Chapter - 3)** (4)

b) *Prove that the voltage and current in purely resistive circuit are in phase.* **(Refer Q.1 of Chapter - 3)** (6)

c) *The series circuit having resistance 5 Ω and capacitance 150 μF is connected to 1-phase, 200 V, 50 Hz AC supply. Calculate -*

i] Capacitive reactance X_C ii] Impedance iii] Current drawn by the circuit iv] Power factor v] Active power and vi] Reactive power. **(Refer Q.21 of Chapter - 3)** (8)

OR

Q.2 a) *What is resonance in series circuit ? Derive the expression for the resonant frequency of a series RLC circuit.* **(Refer Q.30 and Q.32 of Chapter - 3)** (4)

b) *What is admittance ? Which are its two components ? State their units. How the admittance is expressed in polar and rectangular forms.* **(Refer Q.26 of Chapter - 3)** (6)

c) *A coil having resistance of 7 Ω and an inductance of 31.8 mH is connected to 230 V, 50 Hz supply. Calculate : i) The circuit current ii) Phase angle iii) Power factor iv) Power consumed iv) Voltage drop across resistance and inductor.* **(Refer Q.16 of Chapter - 3)** (8)

Q.3 a) *State any four advantages of three phase system.* **(Refer Q.1 of Chapter - 4)** (3)

b) *Derive the relation between line and phase values of currents and voltages for balanced three phase star connected load connected across three phase a.c. supply. Derive the expression for the power consumed by the load.* **(Refer Q.6 of Chapter - 3)** (6)

c) *A 10 kVA, 3300/220 V 1-phase 50 Hz transformer has e.m.f. per turn equal to 10. Calculate : i) Turns on primary side ii) Turns on secondary side iii) Maximum flux in the core iv) Primary and secondary full load current.* **(Refer Q.24 of Chapter - 4)** (8)

OR

Q.4 a) *Derive e.m.f. equation of a single phase transformer.* **(Refer Q.22 of Chapter - 4)** (3)

b) *Three identical impedances each of 6 + j8 Ω are connected in delta across 3-ph, 400 V, 50 Hz ac supply. Calculate i) Line current ii) Power factor iii) Active power iv) Reactive power* **(Refer Q.13 of Chapter - 4)** (6)

c) *A transformer is rated at 100 kVA. At full load, its copper loss is 1200 W and its iron loss is 960 W.*

Calculate : i) Efficiency at full load, 0.8 power factor.

ii) Load kVA at which maximum efficiency will occur.

iii) Maximum efficiency at 0.85 power factor.

(Refer Q.35 of Chapter - 4)

Q.5 a) *State and explain Kirchhoff's laws.* **(8)**

(Refer Q.6 of Chapter - 5) **(4)**

b) *Find equivalent resistance between A and B for the circuit shown in Fig. 1.* **(Refer Q.11 of Chapter - 5)** **(6)**

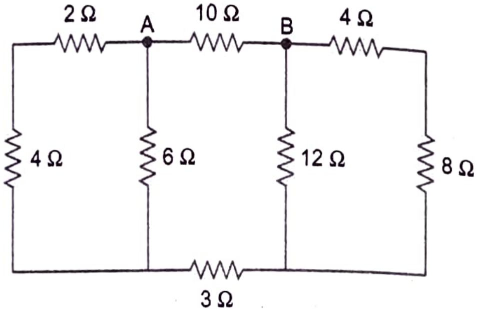


Fig. 1

c) *Find current through branch AB using Kirchhoff's laws.*

(Refer Q.15 of Chapter - 5) **(8)**

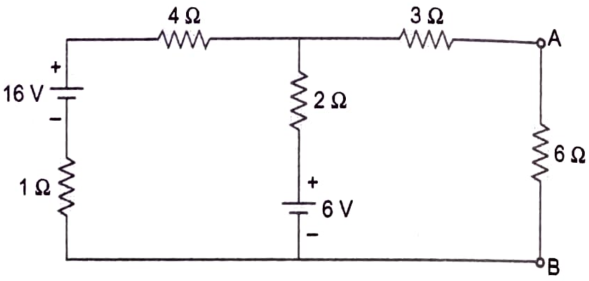


Fig. 2

OR

Q.6 a) *State and explain Superposition theorem.*

(Refer Q.9 of Chapter - 5) **(4)**

b) *Determine effective resistance between A and B.*

(Refer Q.12 of Chapter - 5) **(6)**

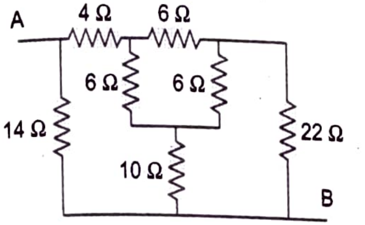


Fig. 3

c) *Apply Thevenin's theorem to calculate current flowing in 5 Ω resistance for the network. (Refer Fig. 4)*

(Refer Q.25 of Chapter - 5) **(8)**

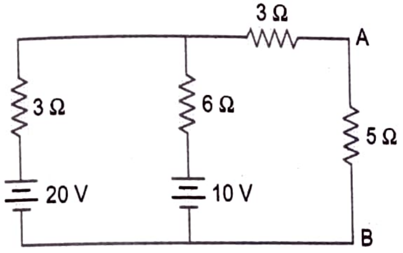


Fig. 4

Q.7 a) *Discuss the effect of temperature on the resistance of various materials with the help of a graph.*

(Refer Q.1 of Chapter - 6) **(3)**

b) *Explain the construction of a lead acid battery.*
(Refer Q.26 of Chapter - 6) (6)

c) *A coil has a resistance of 40 Ω at 25 °C. When its temperature is increased to 110 °C the resistance increases to 50 Ω. Calculate the temperature coefficient of resistance of coil material at*
i) 25 °C ii) 110 °C and iii) 0 °C.
(Refer Q.6 of Chapter - 6) (8)

OR

Q.8 a) *Define temperature coefficient of resistance and state its unit.*
(Refer Q.3 of Chapter - 6) (3)

b) *Explain the construction and working of Lithium-ion battery with the help of neat diagrams.*
(Refer Q.31 and Q.32 of Chapter - 6) (6)

c) *A water pump lifts 50 m^3 of water per hour to a height of 20 m. The overall efficiency of water pump set is 0.60. Find monthly bill, when the pump is used 4 hours a day for a month of 30 days, at the rate of ₹ 5/kWh.*
(Refer Q.19 of Chapter - 6) (8)

SOLVED SAMPLE QUESTION PAPER - 2 [END SEM]
(AS PER 2019 PATTERN)

Time : 2 $\frac{1}{2}$ Hours] **[Max. Marks : 70**

Q.1 (a) *Define inductive reactance, capacitive reactance and power factor.* **(Refer Important Points to Remember on page (3-6), (3-9) and Q.15 of Chapter - 3)** (4)

(b) *Obtain an expression for the power when sinusoidal voltage is applied across series R-L circuit. Draw the circuit diagram and phasor diagram.*
(Refer Q.11 and Q.12 of Chapter - 3) (6)

(c) *An e.m.f given by v = 100 sin 100 πt is impressed across a circuit consisting of resistance of 40 Ω in series with 100 μF capacitor and 0.25 H inductor. Determine : i) r.m.s value of the current, ii) Power consumed. iii) Power factor.*
(Refer Q.24 of Chapter - 3) (8)

OR

Q.2 (a) *Show that the current through purely capacitive circuit leads the applied voltage by 90°.* **(Refer Q.8 of Chapter - 3)** (4)

(b) *Find the expression for current which will flow when a pure inductor of 0.2 H is connected across 230 V, 50 Hz, AC supply. Draw the phasor diagram.*
(Refer Q.7 of Chapter - 3) (6)

(c) *A R-C series circuit is connected across 100 V, 50 Hz supply draws a current of 5 A at a power factor 0.3 leading. Find the value of R and C. Also find power consumed.*
(Refer Q.22 of Chapter - 3) (8)

Q.3 (a) *Explain the working principle of a transformer.*
(Refer Q.18 of Chapter - 4) (3)

(b) *Derive the relation between line and phase values of currents and voltages for balanced three phase delta connected load connected across three phase a.c. supply. Derive the expression for the power consumed by the load.*
(Refer Q.8 of Chapter - 4) (6)

(c) *A single phase 4 kVA transformer has 400 turns on its primary and 1000 secondary turns. The net cross-sectional area of the core is 60 cm^2. When the primary winding is* connected to 500 V, 50 Hz supply. Calculate :

i) the max. value of flux density in the core.

ii) the voltage induced in the secondary winding and

iii) the secondary full load current.

(Refer Q.23 of Chapter - 4)

OR

(8)

Q.4 **(a)** *State the advantages and applications of autotransformer.* **(Refer Q.41 of Chapter - 3)** **(3)**

(b) *With the help of neat circuit diagram, describe the method of testing a single phase transformer by direct loading method .* **(Refer Q.38 of Chapter - 4)** **(6)**

(c) *Three identical impedances each of 6 + j8 Ω are connected in star across 3-ph, 400 V, 50 Hz a.c. supply. Calculate :* *i) Line current ii) Active power iii) Reactive power* **(Refer Q.12 of Chapter - 4)** **(8)**

Q.5 **(a)** *Explain ideal and practical current sources.* **(Refer Q.4 of Chapter - 5)** **(4)**

(b) *Find equivalent resistance between AB for the circuit shown in Fig. 1.* **(Refer Q.5 of Chapter - 5)** **(6)**

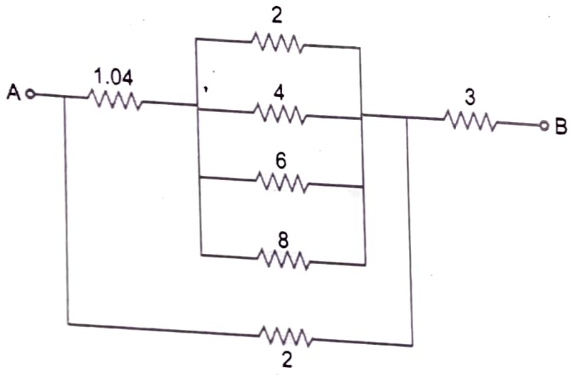


Fig. 1

(c) *Apply superposition theorem to calculate current flowing in 3 Ω resistance for the network.* **(Refer Q.20 of Chapter - 5)** **(8)**

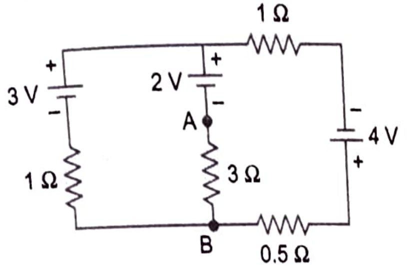


Fig. 2

OR

Q.6 **(a)** *State Thevenin's theorem.* **(Refer Q.23 of Chapter - 5)** **(3)**

(b) *Using Mesh/Loop analysis, calculate current flowing through* R_{BC} *for Fig. 3.* **(Refer Q.14 of Chapter - 5)** **(6)**

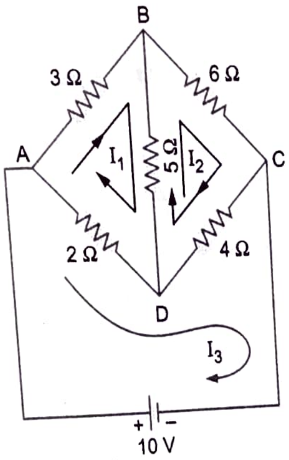


Fig. 3

(c) *Derive equations to convert delta connected resistances to equivalent star connected resistances.*
(Refer Q.9 of Chapter - 5)

(8)

Q.7 (a) *Explain series and parallel grouping of batteries.*
(Refer Q.37 of Chapter - 6)

(3)

(b) *Derive an expression for insulation resistance of a cable.*
(Refer Q.11 of Chapter - 6)

(6)

(c) *An electric kettle is required to raise the temperature of 2 litres of water from 20 °C to 100 °C in 15 mins. Calculate the resistance of the heating element if the kettle is to be used on 200 V supply. Assume efficiency of the kettle to be 80 %. Assume specific heat of water 4180 J/kg-K.*
(Refer Q.20 of Chapter - 6)

(8)

OR

Q.8 (a) *State the advantages and applications of Lithium-ion battery.*
(Refer Q.33 of Chapter - 6)

(3)

(b) *With usual notations, obtain the expression*

$\alpha_2 = \dfrac{\alpha_1}{1+\alpha_1(t_2-t_1)}$ *and hence obtain*

$\alpha_t = \dfrac{\alpha_0}{1+\alpha_0 \cdot t}$ *and then* $\alpha_0 = \dfrac{\alpha_1}{1-\alpha_1 \cdot t}$.

(Refer Q.5 of Chapter - 6)

(6)

(c) *Find the current flowing at the instant of switching 40 W lamp on 240 V supply. Given that working temperature of filament is 2000 °C and temperature co-efficient of resistance of filament at 15 °C is 0.005 /°C.*
(Refer Q.9 of Chapter - 6)

(8)

SOLVED SAMPLE QUESTION PAPER - 3 [END SEM]

(AS PER 2019 PATTERN)

Time : $2\frac{1}{2}$ **Hours]** **[Max. Marks : 70**

Q.1 (a) *Derive an expression for the instantaneous power in a purely resistive circuit excited by sinusoidal voltage.*
(Refer Q.2 of Chapter - 3) (4)

(b) *Find the expression for current which will flow when a pure inductor of 0.2 H is connected across 230 V, 50 Hz, AC supply. Draw the phasor diagram.*
(Refer Q.7 of Chapter - 3) (6)

(c) *A coil having resistance of 7 Ω and an inductance of 31.8 mH is connected to 230 V, 50 Hz supply. Calculate : i) The circuit current ii) Phase angle iii) Power factor iv) Power consumed iv) Voltage drop across resistance and inductor.* **(Refer Q.16 of Chapter - 3)** (8)

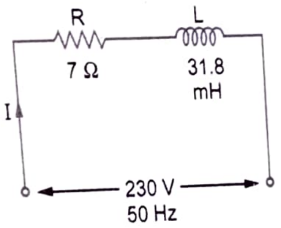


Fig. 1

OR

Q.2 (a) *State any four characteristics of series resonance.*
(Refer Q.31 of Chapter - 3) (4)

(b) For a single-phase a.c circuit, the applied voltage is $v = V_m \sin \omega t$ and current drawn is $i = I_m \sin (\omega t - \phi)$. Derive expression for average power. Draw waveforms of voltage, current and instantaneous power over one cycle of voltage. **(Refer Q.12 of Chapter - 3)** **(6)**

(c) A R-C series circuit is connected across 100 V, 50 Hz supply draws a current of 5 A at a power factor 0.3 leading. Find the value of R and C. Also find power consumed. **(Refer Q.22 of Chapter - 3)** **(8)**

Q.3 **(a)** Define phase sequence and symmetrical three phase system. **(Refer Q.2 and Q.3 of Chapter - 4)** **(3)**

(b) Draw a complete phasor diagram for three phase delta connected inductive load connected across three phase a.c. supply. **(Refer Q.9 of Chapter - 4)** **(6)**

(c) Explain the construction and working principle of transformer. **(Refer Q.18 and Q.19 of Chapter - 4)** **(8)**

OR

Q.4 **(a)** Explain the various losses in a transformer. In which part these losses occur ? How to minimize them ? **(Refer Q.30 of Chapter - 4)** **(3)**

(b) A single phase 50 Hz transformer has 300 primary turns and 750 secondary turns. The net cross-sectional area of the core is 64 cm^2. If the primary induced emf is 400 V, find :
i) Maximum flux in the core
ii) Maximum flux density in the core
iii) emf induced in the secondary.
(Refer Q.25 of Chapter - 4) **(6)**

(c) Derive the relation between line and phase values of currents and voltages for balanced three phase star connected load connected across three phase a.c. supply. Derive also power consumed by the load. **(Refer Q.6 of Chapter - 4)** **(8)**

Q.5 **(a)** Explain ideal and practical current sources. **(Refer Q.4 of Chapter - 5)** **(4)**

(b) Find equivalent resistance between A and B for the circuit shown in Fig. 2. **(Refer Q.11 of Chapter - 5)** **(6)**

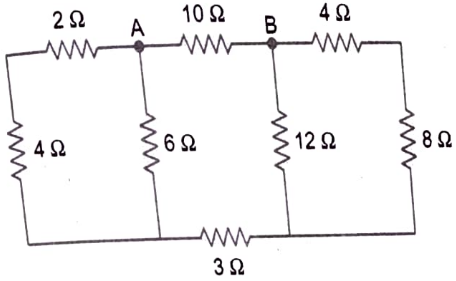


Fig. 2

(c) Derive an equations to convert star connected resistances to equivalent delta connected resistances. **(Refer Q.10 of Chapter - 5)** **(8)**

OR

Q.6 **(a)** State and explain Kirchhoff's laws. **(Refer Q.6 of Chapter - 5)** **(4)**

(b) State and explain Superposition theorem. **(Refer Q.19 of Chapter - 5)** **(6)**

(c) Apply Thevenin's theorem to calculate current flowing in 5 Ω resistance for the network. **(Refer Q.25 of Chapter - 5)** **(8)**

Q.7 **(a)** *What is semiconductor ? Give two examples. Explain the effect of temperature on semiconductors.* **(Refer Q.2 of Chapter - 6)** **(3)**

(b) *With a neat diagram describe the construction of a lead acid cell.* **(Refer Q.26 of Chapter - 6)** **(6)**

(c) *A water pump lifts 50 m^3 of water per hour to a height of 20 m. The overall efficiency of water pump set is 0.60. Find monthly bill, when the pump is used 4 hours a day for a month of 30 days, at the rate of ₹ 5/kWh.* **(Refer Q.19 of Chapter - 6)** **(8)**

OR

Q.8 **(a)** *Explain the significance of depth of discharging.* **(Refer Q.35 of Chapter - 6)** **(3)**

(b) *A single core cable has its conductor diameter as 2 cm and outer diameter as 5 cm. The resistivity of conductor and insulator are 1.73×10^{-8} Ω-m and 8×10^{12} Ω-m respectively. Calculate resistance of conductor and insulation for a cable of 100 meter.* **(Refer Q.12 of Chapter - 6)** **(6)**

(c) *A coil has a resistance of 40 Ω at 25 °C. When its temperature is increased to 110 °C the resistance increases to 50 Ω. Calculate the temperature coefficient of resistance of coil material at i) 25 °C ii) 110 °C and iii) 0 °C.* **(Refer Q.6 of Chapter - 6)** **(8)**

SOLVED SAMPLE QUESTION PAPER - 4 [END SEM]

(AS PER 2019 PATTERN)

Time : $2\frac{1}{2}$ **Hours]** **[Max. Marks : 70**

Q.1 **(a)** *The expression of the alternating current is given by* $i = 5.48 \sin \omega t$. *Calculate : i) the average value, ii) rms value of the current iii) power consumed if the current is passed through a resistance of 10 Ω* **(Refer Q.3 of Chapter - 3)** **(4)**

(b) *Derive the expressions for current and power for purely capacitive circuit when the voltage applied to it is $v(t) = V_m \sin \omega t$. Draw the corresponding phasor diagram.* **(Refer Q.8 of Chapter - 3)** **(6)**

(c) *A coil of inductance 15 mH and resistance 25 Ω resistance is connected in series with a capacitor 'C' across 230 V, 50 Hz supply. Find the value of capacitor so that circuit draws maximum current. What will be the power factor and power consumed ?* **(Refer Q.34 of Chapter - 3)** **(8)**

OR

Q.2 **(a)** *Define impedance and sketch impedance triangle for R-L series circuit.* **(Refer Q.13 of Chapter - 3)** **(4)**

(b) *Find the expression for current when $v = 282.84 \sin (314\ t)$ V is applied to coil having resistance 10 ohm and inductance 0.1 H. Also calculate the power consumed.* **(Refer Q.17 of Chapter - 3)** **(6)**

(c) *An e.m.f given by $v = 100 \sin 100\pi t$ is impressed across a circuit consisting of resistance of 40 Ω in series with 100 μF capacitor and 0.25 H inductor. Determine :*
i) r.m.s value of the current ii) power consumed
iii) power factor. **(Refer Q.24 of Chapter - 3)** **(8)**

Q.3 **(a)** *A 10 kVA, 3300/220 V 1-phase 50 Hz transformer has e.m.f. per turn equal to 10. Calculate :*

i) Turns on primary side *ii) Turns on secondary side*

iii) Maximum flux in the core

iv) Primary and secondary full load current

(Refer Q.24 of Chapter - 4) **(3)**

(b) *A transformer is rated at 100 kVA. At full load, its copper loss is 1200 W and its iron loss is 960 W. Calculate :*

i) Efficiency at full load, 0.8 power factor.

ii) Load kVA at which maximum efficiency will occur.

iii) Maximum efficiency at 0.85 power factor.

(Refer Q.35 of Chapter - 4) **(6)**

(c) *Derive the relation between line and phase values of currents and voltages for balanced three phase star connected load connected across three phase a.c. supply. Derive also power consumed by the load.* **(Refer Q.8 of Chapter - 4)** **(8)**

OR

Q.4 **(a)** *With the help of neat circuit diagram, describe the method of testing a single phase transformer by direct laoding.*

(Refer Q.38 of Chapter - 4) **(3)**

(b) *Define regulation of transformer. State its expression. How it depends on the load power factor ? Sketch the regulation characteristics.* **(Refer Q.29 of Chapter - 3)** **(6)**

(c) *A delta connected load draws a line current of 15 ampere at a lagging power factor of 0.85 from a 400 V 50 Hz, 3 phase supply. Find the resistance and inductance of each phase. If the same load is now connected in star, calculate the line current and total power consumed.*

(Refer Q.15 of Chapter - 4) **(8)**

Q.5 **(a)** *Explain ideal and practical voltage sources.*

(Refer Q.3 of Chapter - 5) **(3)**

(b) *Find current through branch AB using Kirchhoff's laws.*

(Refer Q.15 of Chapter - 5) **(6)**

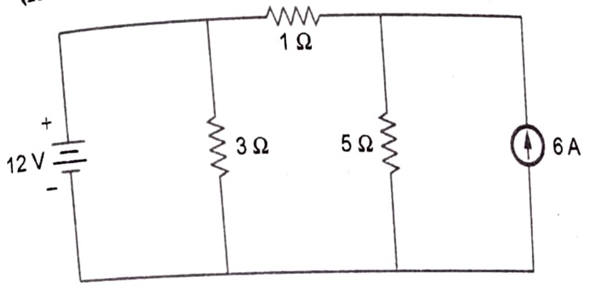


Fig. 1

(c) *Calculate the current through all resistance using superposition principle.* **(Refer Q.22 of Chapter - 5)** **(8)**

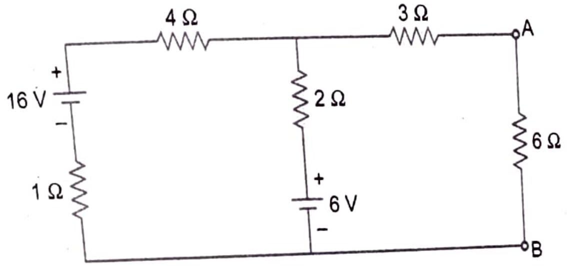


Fig. 2

OR

Q.6 **(a)** *Define star and delta connection of resistances.*

(Refer Q.8 of Chapter - 5) **(3)**

(b) *Determine effective resistance between A and B.*

(Refer Q.12 of Chapter - 5) **(6)**

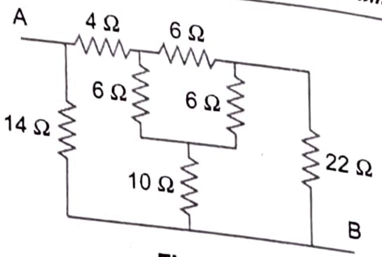


Fig. 3

(c) *Apply Thevenin's theorem, to calculate current flowing in 10 ohm resistance, for the circuit shown in Fig. 4.* **(Refer Q.26 of Chapter - 5)** **(8)**

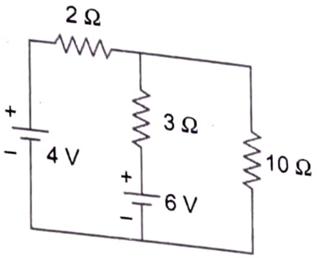


Fig. 4

Q.7 **(a)** *State any three conditions of fully charged lead acid battery.* **(Refer Q.30 of Chapter - 6)** **(3)**

(b) *Explain the parallel and series-parallel grouping of batteries with neat circuit diagrams.* **(Refer Q.37 of Chapter - 6)** **(6)**

(c) *Define insulation resistance ? Derive an expression for insulation resistance of the cable. State the factors affecting insulation resistance.* **(Refer Q.11 of Chapter - 6)** **(8)**

OR

Q.8 **(a)** *List the safety precautions to be taken in battery maintenance.* **(Refer Q.36 of Chapter - 6)** **(3)**

(b) *A belt driven pulley of 0.4 m in diameter rotates at a speed of 4 revolutions per second. The tension in the tight side of the belt is 420 N and in the slack side 80 N. Calculate : i) The torque on pulley ii) The power developed* **(Refer Q.15 of Chapter - 6)** **(6)**

(c) *Explain the working of lithium ion battery.* **(Refer Q.32 of Chapter - 6)** **(8)**

SOLVED SAMPLE QUESTION PAPER - 5 [END SEM]
(AS PER 2019 PATTERN)

Time : $2\frac{1}{2}$ Hours] **[Max. Marks : 70**

Q.1 **(a)** *Define conductance and susceptance. State their units.* **(Refer Q.26 of Chapter - 3)** **(4)**

(b) *Derive the expressions for current and power for purely inductive circuit when the voltage applied to it is $v(t) = V_m \sin \omega t$. Draw the corresponding phasor diagram.* **(Refer Q.5 of Chapter - 3)** **(6)**

(c) *The resistance of 5 Ω is connected across 200 V, 50 Hz 1-phase a.c. supply. The voltage across the resistance is 50 V. Calculate :*

i) Voltage across inductance ii) Value of inductance

iii) Power and iv) Power factor

(Refer Q.18 of Chapter - 3) **(8)**

OR

Q.2 **(a)** *Derive the equation for the resonant frequency in series RLC circuit. Draw the phasor diagram.* **(Refer Q.32 of Chapter - 3)** **(4)**

(b) Sketch and explain the phasor diagram of RLC series circuit for i) $X_C > X_L$ ii) $X_C < X_L$ iii) $X_C = X_L$. **(Refer Q.23 of Chapter - 3)** **(6)**

(c) Derive an expression for current drawn and power consumed by a circuit consisting of 'R' and 'C' connected in series across $v = V_m \sin \omega t$ supply. **(Refer Q.19 of Chapter - 3)** **(8)**

Q.3 **(a)** Compare core type and shell type transformers. **(Refer Q.20 of Chapter - 4)** **(3)**

(b) State the equations for real power, apparent power and reactive power for three phase balanced load. Draw the power triangle. **(Refer Q.10 of Chapter - 4)** **(6)**

(c) Draw a complete phasor diagram for three phase star connected inductive load connected across three phase a.c. supply. **(Refer Q.7 of Chapter - 4)** **(8)**

OR

Q.4 **(a)** Derive the e.m.f. equation of a transformer. **(Refer Q.22 of Chapter - 4)** **(3)**

(b) Three identical impedances each of 6 + j8 Ω are connected in star across 3-ph, 400 V, 50 Hz a.c. supply. Calculate : i) Line current ii) Active power iii) Reactive power **(Refer Q.12 of Chapter - 4)** **(6)**

(c) A 600 kVA transformer has iron losses of 4 kW and half load copper losses are 2 kW. Calculate the efficiency of transformer at

i) Half load 0.8 p.f. lagging and

ii) Full load 0.8 p.f. lagging.

(Refer Q.34 of Chapter - 4) **(8)**

Q.5 **(a)** Explain ideal and practical current sources. **(Refer Q.4 of Chapter - 5)** **(4)**

(b) For the circuit shown in Fig. 1. Find the current flowing through PQ using Kirchhoff's laws. **(Refer Q.18 of Chapter - 5)** **(6)**

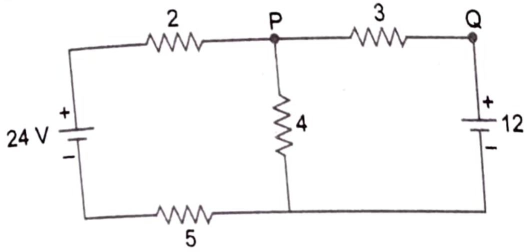


Fig. 1

(c) Using Mesh/Loop analysis, calculate current flowing through R_{BC} for Fig. 2. **(Refer Q.14 of Chapter - 5)** **(8)**

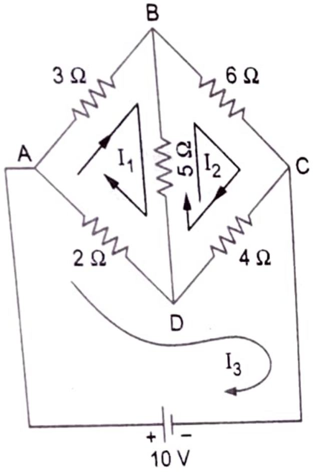


Fig. 2

OR

Q.6 **(a)** List the various steps used for the loop analysis of a network. **(Refer Q.13 of Chapter - 5)** **(4)**

(b) Derive equations to convert delta connected resistances to equivalent star connected resistances. **(Refer Q.9 of Chapter - 5)** (6)

(c) Using Thevenin's theorem, determine the value of current flowing through 6 Ω resistance. **(Refer Q.27 of Chapter - 5)** (8)

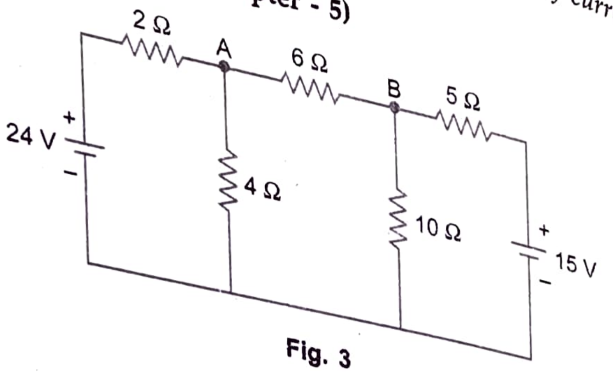


Fig. 3

Q.7 **(a)** Explain the series grouping of batteries with neat circuit diagram. **(Refer Q.37 of Chapter - 6)** (3)

(b) With usual notations, obtain the expression $\alpha_2 = \frac{\alpha_1}{1+\alpha_1(t_2-t_1)}$ and hence obtain $\alpha_t = \frac{\alpha_0}{1+\alpha_0 \cdot t}$ and then $\alpha_0 = \frac{\alpha_1}{1-\alpha_1 \cdot t}$. **(Refer Q.5 of Chapter - 6)** (6)

(c) An electric motor runs at 600 rpm and produces a torque of 210 N-m. The motor efficiency is 88 %. Find motor input power and current drawn when motor is fed at 400 V DC supply. **(Refer Q.21 of Chapter - 6)** (8)

OR

Q.8 **(a)** *State the advantages and applications of lithium ion battery.* **(Refer Q.33 of Chapter - 6)** (3)

(b) *In a hydro electric generating station, the head of water is 425 m. If 1250 liters of water are required to generate 1 kWh of electric energy, find the overall efficiency. Assume 1 liter = 1 kg.* **(Refer Q.22 of Chapter - 6)** (6)

(c) *If the temperature coefficient of resistance for copper wire is 0.00393 per degree celsius at 20 °C. Find the temperature coefficient of resistance at [i] 50 °C and [ii] 70 °C.* **(Refer Q.10 of Chapter - 6)** (8)

END...